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CASCADE IMPACTOR NETWORK

Robert E. Lee, Jr., et al

National Environmental Research Center

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CASCADE IMPACTOR NETWORK

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Robert E. Lee, Jr.

and

Stephen Goranson

National Environmental Research Center

ENVIRONMENTAL PROTECTION AGENCY
Office of Administration
Research Triangle Park, North Carolina
July 1972

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ABSTRACT

An experimental network of modified cascade impactors was set up, as part of the National Air Surveillance Network, to determine gravimetrically the particle size distribution of suspended particulate matter in the air in six urban areas. During 1970, samples were collected at a flow rate of 5 to 6 cfm for a 24-hour period once every 2 weeks according to a prearranged schedule. The modified cascade impactor, the analytical methodology, and the computer processing of data are described.

Results of the first year's operation indicate that suspended particulate matter in urban air is predominantly submicron in size (expressed as equivalent spheres of unit density). Individual and composite particle size distribution curves were appoximately log-normal. Variations in the quarterly composites of mass median diameter, various size fractions less than or equal to 1 and 2 microns, and the degree of particle dispersion expressed by the geometric deviation generally followed seasonal patterns. Future expansion of the network is discussed.

Key Words: size distributions, particulate matter, cascade impactors, aerosols.

CASCADE IMPACTOR NETWORK

INTRODUCTION

Characterization of suspended particulate pollutants in ambient air is usually limited to estimating the quantity of total suspended particulate (micrograms of particulate per cubic meter of air), and determining the gross concentrations of a number of chemical components. The National Air Surveillance Networks (NASN) of the U.S. Environmental Protection Agency (EPA) operate a nationwide system of high volume (Hi-Vol) air samplers; particulates are collected on glass-fiber filters for a 24-hour period and analyzed by gravimetric and chemical methods. Although these measurements can give some indication of the general pollution level in an area, they do not provide information concerning the size distribution of total suspended particulate matter.

Because the degree of respiratory penetration and retention is a direct function of aerodynamic particle size, knowledge of the particle size distribution of suspended particulates is essential in assessing the inhalation health hazard.[1] The particle size, composition, and concentration of aerosol constituents determines the extent of visibility reduction,[2] particle-particle and particle-gas interactions, soiling, deterioration of materials, and a wide range of atmospheric phenomena. Furthermore, the particle size of suspended particulates is important in meteorology (particularly as it affects formation of precipitation) and in geophysics (particulates can scatter solar radiation back into space). Until now, data on particle size distribution of suspended particulates have been difficult to obtain because available fractionating devices either required excessively long sampling periods to collect sufficient material for gravimetric or chemical analysis, or provided inadequate resolution of sizes. In addition, the previously available size classifiers generally were expensive, were difficult to operate, and were of limited usefulness in a network operation; often, too, the collection surfaces were not amenable to gravimetric or to chemical analysis. Recently, however, Lee and Flesch[3] described a high-volume particle fractionating cascade impactor that overcame most of these disadvantages. This fractionater was adapted from an Andersen* cascade impactor,[4] a commercially available device that has been used for some limited air pollution studies.[5,6]

**Mention of a specific commercial product or a company name does not constitute endorsement by the Environmental Protection Agency.*

In an effort to characterize the particle size distribution of suspended particulate matter on a routine basis, an experimental network of the modified cascade impactors was established in six urban areas in January 1970. Cascade impactors were installed at the NASN Continuous Air Monitoring Project (CAMP) stations in Chicago, Washington, D.C., Philadelphia, St. Louis, Cincinnati, and Denver. A 24-hour sample was collected once every 2 weeks according to a schedule established earlier for an EPA study of pollutant effects. This report describes results that were obtained from the first year's operation of the network, some problems that were encountered in the operation, and plans that were made for expanding the network.

MODIFIED ANDERSEN SAMPLER

The Andersen cascade impactor fractionates particles in a series of six collection stages according to the aerodynamic dimension of the particles. Particles pass through a series of jets, 400 per stage, with progressively smaller cross sections. At each jet, a fraction of the particles is impacted on a collection plate; the range of particle sizes collected on a stage depends on the jet velocity of the stage, on the jet-to-collection-surface distance, and on the collection characteristics of the previous stage. Particles that are not collected on the first stage follow the air stream around the collection plate to the next stage until the jet velocity is sufficient for impaction.

By removing the sixth stage of the Andersen sampler and placing a 4-inch-diameter filter downstream to collect the small unimpacted particles, one can operate the sampler at a flow rate of 5 to 6 cubic feet per minute (cfm). Operation requires a vacuum pump of about 8 inches of mercury for sustained sampling periods.

A diagram of the modified sampler is given in Figure 1. The spring clamps, which hold the stages tightly together, must be shortened when the sixth stage of the commercial sampler is removed. The backup filter holder can accommodate glass fiber or membrane filters 4 inches in diameter. A Gast carbon vane rotary pump, model 0822, is housed in a vented shelter. The cascade impactor and the backup filter are protected from precipitation and from large debris by a removable rain shield. The impactor with the backup filter holder is shown both with and without the rain shield in Figure 2. The air flow rate can be determined by measuring the pressure drop across an orifice, approximately 0.25 inch in diameter, with a magnehelic or other pressure gauge having a capacity of 50 inches of water. Pressure drop across the orifice is calibrated as a function of flow rate by placing a dry test meter at the inlet end of the sampler and varying the air flow with an air bleed on the vacuum pump.

DESCRIPTION OF GRAVIMETRIC METHOD

A disk of aluminum foil 3.25 inches in diameter, as shown in Figure 3, is conditioned in a room having controlled temperature and humidity for 24 hours and is weighed to the nearest microgram on a micro-analytical balance (Kahn Electro Balance). In the work reported here, all the weighings were done on a micro-electro balance fitted with a weighing chamber and adapted to permit below-the-pan weighing by suspending the aluminum foil disk from a wire attached to the balance beam, as shown in Figure 3. Both the electro-balance and the collection surfaces were housed in a room maintained at a relative humidity of 50 percent and a temperature of 72°F.

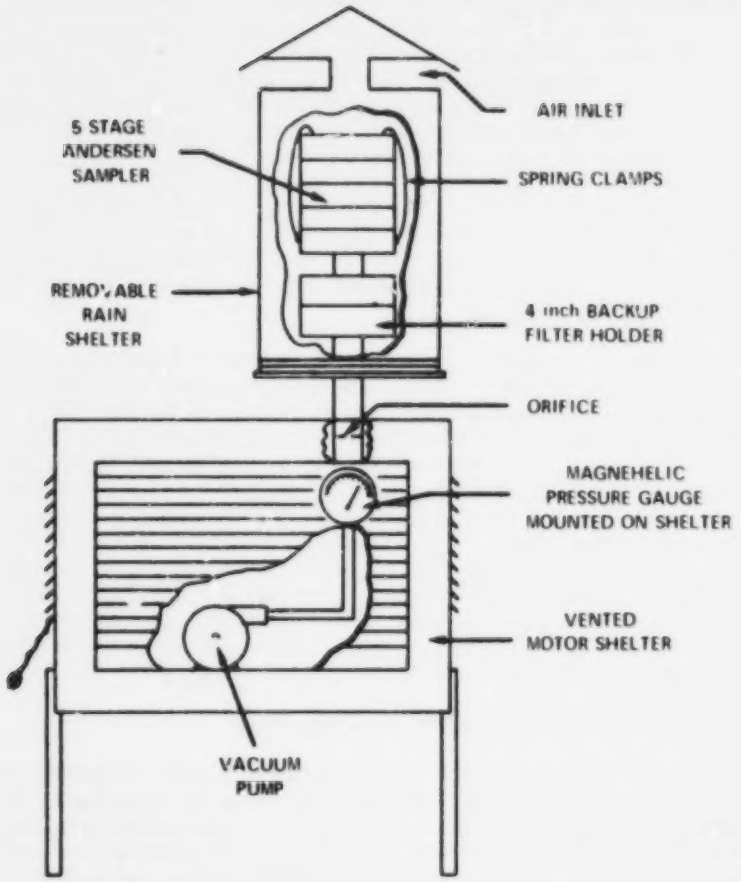

Figure 1. Diagram of the modified Andersen impactor and shelter.

Figure 2. NASN cascade impactor with and without rain shield.

Reproduced from best available copy.

Figure 3. Disk of aluminum foil used as collection surface (top). Method of weighing the cascade impactor collection surface (bottom).

To collect a sample, a preweighed aluminum disk is placed on top of each stainless steel collection plate in the modified Andersen cascade impactor. A conditioned and weighed 4-inch-diameter membrane filter of 3.0 micron pore size and with a nylon mesh reinforcement is placed in the backup filter holder. All collection surfaces are handled with forceps. The sampler is operated for a 24-hour period; average flow rate is calculated from the beginning and the ending air flow values. After sampling, the aluminum collection disks and the membrane filter are folded in half with the sample side touching, are placed in glassine envelopes, and are returned to the laboratory, where they are conditioned in the temperature-humidity controlled atmosphere for 24 hours before weighing.

DETERMINATION OF PARTICLE SIZE FRACTIONATION CHARACTERISTICS

The high collection rate (5 to 6 cfm) of the modified cascade impactor precludes dynamic laboratory calibration such as described by Flesch *et al.*[7] It is experimentally difficult to maintain an aerosol of known particle size when a large portion of the aerosol is removed with the impactor. Consequently, the particle size fractionation characteristics of the sampler were determined theoretically.

According to studies by Mercer[8] and by Ranz and Wong,[9] the effective cutoff diameter (ECD) in microns for each stage of an impactor can be determined by use of the dimensionless inertial impactor parameter, Ψ.

$$\sqrt{\Psi} = \left[\frac{V_j \rho C D_\rho^2}{18 \eta D_j} \right]^{1/2}$$

where V_j = jet velocity

ρ = particle density

C = Cunningham correction factor

η = viscosity of medium

D_j = diameter of jet

D_ρ = diameter of particle

For round jets where $s/D_j > 2$ (s is the jet-to-collection-surface distance) as in the Andersen, $\Psi^{1/2} = 0.38$. Thus, the ECD, which is the quantity $(\rho C^{1/2} D_p)$, can be calculated for various flow rates. Because flow conditions are not appreciably altered at air flow rates higher than that ordinarily used with the conventional Andersen impactor (1 cfm), the inertial impaction parameter can be expected to predict fairly accurate ECD values at these flows.

The variation of ECD with flow rate for each stage of the Anderson sampler, calculated from the Mercer-Ranz-Wong theory, is summarized in Table 1. With increasing flow rate, sharp increases in ECD occur on the upper stages, which collect the larger particles. The ECD for each stage changes very little, however, when the flow rate is increased beyond about 4 cfm.

Table 1. EFFECTIVE CUTOFF DIAMETER FOR CASCADE IMPACTOR AS FUNCTION OF FLOW RATE

Impactor stage	Effective cutoff diameter, μ
1	$\frac{7.22}{\sqrt{\text{cfm}}}$
2	$\frac{4.92}{\sqrt{\text{cfm}}}$
3	$\frac{3.38}{\sqrt{\text{cfm}}}$
4	$\frac{2.19}{\sqrt{\text{cfm}}}$
5	$\frac{1.40}{\sqrt{\text{cfm}}}$

COMPUTER PROGRAM

A small scientific computer was used to calculate size distribution data including: (1) total particulate concentration in micrograms per cubic meter ($\mu g/m^3$), (2) mass median diameter (MMD) in microns, (3) standard geometric deviation, (4) percent particle mass less than or equal to 1 micron in diameter, and (5) percent particle mass less than or equal to 2 microns in diameter. The input data are the net particulate weights in micrograms for each of the five impactor stages and the backup filter, and the average flow rate for each stage. The ECD for each stage is determined from the average air flow rate as previously described.

$$ECD(I) = C(I)/\sqrt{R}$$

where $ECD(I)$ = the effective cutoff diameter for Stage I ($I = 1\text{-}5$)

$C(I)$ = a constant related to Stage I

R = the air flow rate in cfm

Next, using the net weight data, the cumulative weights are calculated:

$$CUM\ WT(I) = \sum_{J \leq I} \text{Net wt.}(J)$$

where $I = 1, 2, 3, 4, 5, 6$, where 1 through 5 are impactor stages and 6 is the backup filter

The cumulative percent mass greater than each stage is calculated from:

$$CUM\%(I) = \frac{CUM\ WT(I)}{CUM\ WT(6)} X\ 100$$

A size distribution curve is prepared by plotting the logarithm of the ECD for each stage as a function of the cumulative percent mass less than or equal to each stage (100-CUM % (I)) on a normal probability scale; a standard least-squares linear regression is calculated to determine the best fitting line. An example of the calculation is given in Figure 4; the corresponding size distribution curve is shown in Figure 5.

CINCINNATI OH 04/19/70

SIZE DISTRIBUTION TABLE

ANDERSEN STAGE	NET WT. UG.	CUM.WT. UG.	CUM. PC	ECD U
1	2390.	2390.	15.22	3.19
2	830.	3220.	20.51	2.17
3	741.	3961.	25.23	1.49
4	990.	4951.	31.54	0.96
5	2386.	7337.	46.74	0.61
BACKUP FILTER	836C.	15697.	100.00	

AIR FLOW RATE = 5.11 CFM
AIR VOLUME = 208.3 M3

TOTAL PARTICULATE CONCENTRATION = 75.3 UG/M3

MASS MECIAN DIAMETER = C.48 MICRONS
STANDARD GEOMETRIC DEVIATION = 5.83

PER CENT LESS THAN 1 MICRON = 66.
PER CENT LESS THAN 2 MICRON = 79.

Figure 4. Example of computer printout.

Because the particle size of total suspended particulate is nearly log-normally distributed, the mass median diameter is found at the 50 percent mass cumulative point and the standard geometric deviation is calculated directly from the ratios:

$$\sigma g = \frac{84.13\%\ \text{size}}{50\%\text{size}} \text{ or } \frac{50\%\ \text{size}}{15.87\%\ \text{size}}$$

The size distribution lines are also used to determine the percentages of particulate mass equal to or less than 1 and 2 microns in diameter. These size parameters are printed out directly on the computational sheet as shown in the sample calculation.

One option of the program is that composite curves may be computed by use of data from the individual distributions for 1 quarter, 1 year, or any other desired time interval. To determine composite distributions, an average air flow rate is found and average net weights are determined for each stage; the resultant ECD's are plotted against cumulative percent mass, as in the individual plots.

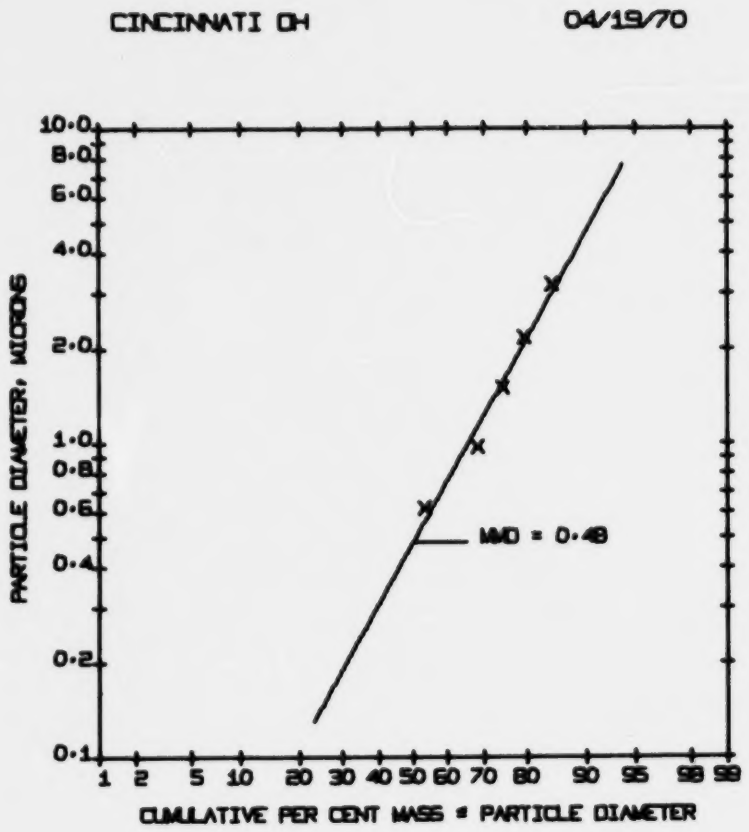

Figure 5. Example of computer-plotted particle size distribution curve.

RELATIONSHIP OF CASCADE IMPACTOR TO HIGH–VOLUME SAMPLER

Because sampling with high-volume air samplers is the method used most commonly in the United States for determining total suspended particulate matter, it is important to relate concentration measurements determined with the cascade impactor sampler to Hi-Vol concentration measurements so that comparisons can be made. During a recent study in England,[10] measurements of suspended particulate concentrations ($\mu g/m^3$) determined with a cascade impactor were compared with measurements determined with a high-volume air sampler. The instruments were operated concurrently for 24-hour sampling periods. A total of 101 sample pairs were collected at sites in London, at Kew Observatory, a suburb of London, and at Eskdalemuir Observatory in southern Scotland, a nonurban site selected to provide "background" measurements of particulate levels. The coefficient of correlation between the two samplers was +0.94, indicating a high degree of association between the methods. Regression equations were developed so that concentration measurements made with the cascade impactor (Y) could be converted to equivalent measurements made with the high-volume sampler (X):

$$Y = 29.158 + 0.507\,X$$

where $S_{y.x} = 10.943$

$$X = 42.650 + 1.742\,Y$$

where $S_{x.y} = 20.320$

Measurements with the cascade impactor exhibited a marked dependence on particulate concentrations. Concentrations measured with the cascade impactor sampler are generally higher than those measured with the Hi-Vol sampler at nonurban sites, where particulate concentrations are low; however, in urban areas, where particulate concentrations are relatively high, concentrations measured with the cascade impactor sampler are generally lower than the corresponding concentrations measured with the Hi-Vol. It appears that the membrane filter, which is placed downstream past the last impactor stage, may be more efficient in collecting submicron size particles, predominately by electrostatic attraction, than the glass fiber filters used in the Hi-Vol; this would account for the higher cascade impactor measurements at nonurban areas. Lower concentrations measured with the cascade impactor in more heavily polluted atmospheres may be explained in part by wall losses on the inner surfaces of the cascade impactor. No sigificant difference in the

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relationship between the two sampling methods was observed in the heating season compared with the nonheating season.

OPERATION OF CASCADE IMPACTOR NETWORK

At 3-month intervals, each station operator was provided with a supply of collection surfaces consisting of 5 preweighed aluminum disks and a membrane filter, each stored in an individual glassine envelope. The six envelopes were placed in a cardboard folder, that was then placed along with a data sheet in a mailing envelope. Each operator was supplied with instructions for operating the impactor and with a set of forceps for handling the collection surfaces.

In accordance with a random sampling schedule, the operator removed the cascade impactor and backup filter holder assembly from the sampler body and at an inside workbench placed the appropriate collection surface on the corresponding impactor stage. He then replaced the impactor assembly on the sampler body, which was connected to a 24-hour timer. After a 5-minute warmup period, he recorded the initial flow reading on the data sheet. He also took a final reading just before shutting off the sampler at the end of the 24-hour period. All samples were collected from midnight to midnight.

After sampling, the operator took the cascade impactor assembly indoors, carefully removed the sample collection surfaces with forceps, folded the surfaces in half with the sample side touching, and returned the collected surface to its original glassine envelope. He then noted on the data sheet all pertinent information, including, sampling site, date of sample, beginning and ending flow readings, and unusual weather conditions. The entire folder was mailed to a NASN laboratory in Cincinnati for gravimetric analysis.

RESULTS AND DISCUSSION

Early in the sampling program, several operational problems contributed to the loss of a number of samples. The most important of these problems concerned the difficulty of placing the membrane filter properly in the backup filter holder. Because of improper placement, the filter could not be sealed in the filter holder, and a portion of the aerosol was lost.

After several sampling runs, however, the operators mastered the technique of changing and folding the collection surfaces and thus increased the subsequent number of valid samples. Barring a clearly recognized sampling error, such as inconsistent reporting of flow rate or visible leaks around the collection surfaces, the samples were accepted as valid. Occasional difficulties in weighing the membrane filters were overcome by use of a polonium radiation source to reduce the surface charge and by careful temperature and humidity control of the weighing-room atmosphere. No attempt was made to chemically analyze the particulate fractions, although analyses of selected components are planned at a future time.

Data on particulate concentrations and on various particle size parameters for each of the sampling sites are summarized in Tables 2 through 7. Examination of these tables indicates that the concentration of suspended particulate matter measured with the cascade impactor was highest in August at Philadelphia, St. Louis, Chicago, and Cincinnati. Similarly, high particulate concentrations were measured at Washington, D.C. in late July and early August; the third highest concentration for the year, at Denver, was also measured in August. The lowest particulate concentrations at Washington, D.C., St. Louis, Chicago, and Cincinnati were measured in mid-November. The lowest value at Philadelphia was measured in December, and at Denver, in October.

Particle size distribution curves for each sampling site are given in the Appendix. Size distribution curves for most of the sampling sites were log-normal, although the distributions at Washington, D.C. appeared to be somewhat skewed. Although the mass mediam diameters at all sites were predominantly submicron, mass median diameters greater than 1 micron were found in individual samples collected at all locations. The largest number of samples in which the mass median diameter was greater than 1 micron was collected at St. Louis (7 of 22 samples). Only 1 of 23 samples collected at Washington, D.C. exhibited a mass median diameter greater than 1 micron. Except for Chicago, the mass median diameters were lowest in the spring and highest from October through December.

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Examination of Tables 2 through 7 reveals that, with some exceptions, the size distribution of suspended particulate matter was relatively broad in samples collected from March through June at most sites, as indicated by the relatively large standard geometric deviation. A trend toward a comparatively narrower distribution of particle sizes, revealed by small standard geometric deviation values, occurred after June. At all sites, the degree of particle dispersion varied considerably among individual samples, an indication that localized conditions such as precipitation and air turbulence significantly influence the distribution of particles. For example, during periods of rain, the washout of large particles that represent a major portion of aerosol mass leaves a relatively broad distribution of small particles. On the other hand, atmospheric turbulence may cause reintrainment of predominantly large particles and thereby produce a relatively narrow distribution of particle sizes.

Table 2. SIZE DISTRIBUTION MEASUREMENTS, CHICAGO, ILLINOIS

Sampling date, 1970	Concentration, $\mu g/m^3$	Mass median diameter, μ	Standard geometric deviation	% Particle mass, $\leq 1\ \mu$	% Particle mass, $\leq 2\ \mu$
January 13	110.4	2.96	8.43	31	43
February 25	111.1	3.14	24.62	37	45
March 9	103.1	2.40	12.70	37	48
March 22	68.0	1.28	4.90	44	61
April 8	86.7	0.48	21.86	60	68
April 19	60.2	0.39	2.45	85	97
May 7	92.4	0.47	12.30	62	72
June 2	57.8	0.26	10.18	72	81
June 12	119.1	0.93	6.40	52	66
June 16	80.1	0.70	4.88	59	75
July 4	43.7	0.05	15.43	85	90
July 14	94.7	0.79	4.90	56	72
July 30	78.1	0.56	7.13	62	72
August 11	139.8	0.92	3.03	53	76
August 27	116.7	0.83	6.12	54	69
September 11	125.9	0.49	8.98	63	74
September 20	88.4	0.47	7.65	65	76
October 7	80.5	0.94	8.70	51	64
November 15	54.3	0.61	9.71	59	70
December 5	58.0	0.62	6.66	60	73
December 20	60.5	0.51	6.90	64	76

Quarterly and annual composites of the particle size distribution data for each site are summarized in Table 8. Composite size distribution curves are presented in Appendix A. Except for Denver and St. Louis, the highest average concentrations of suspended particulate were found during the third quarter of 1970; the lowest concentrations were found during the fourth quarter at Chicago, Cincinnati, St. Louis, and Washington, D.C. The highest average annual concentration, 86.5 $\mu g/m^3$, was measured at Chicago; the lowest average annual concentration, 56.3 $\mu g/m^3$, was measured at Washington, D.C. Comparatively low concentrations, 59.7 $\mu g/m^3$ and 58.5 $\mu g/m^3$, were also measured at Denver and Philadelphia, respectively.

Table 8 also reveals the predominantly submicron size of suspended particulate matter measured at all sites. Lowest values for average mass median diameter, except for the value from the single valid sample collected at Cincinnati during the first quarter, were obtained at all sampling sites during the second quarter. The highest average mass median diameters varied with season and with site. The lowest average annual mass median diameter was found in Denver; the highest, in St. Louis.

Table 3. SIZE DISTRIBUTION MEASUREMENTS, CINCINNATI, OHIO

Sampling date, 1970	Concentration, $\mu g/m^3$	Mass median diameter, μ	Standard geometric deviation	% Particle mass $\leq 1\ \mu$	% Particle mass $\leq 2\ \mu$
March 22	61.9	0.37	5.71	72	84
April 8	83.7	0.44	6.79	67	79
April 19	75.3	0.48	5.83	66	79
May 7	51.4	0.26	12.02	71	79
May 23	133.1	0.92	5.60	52	68
June 2	43.8	0.91	10.00	76	85
June 15	74.8	0.66	4.21	62	78
July 4	51.8	0.27	10.68	71	80
July 14	124.4	1.07	3.13	48	71
July 30	69.1	0.80	5.85	55	70
August 10	40.5	0.48	3.91	71	85
August 26	191.7	1.11	4.78	48	65
September 11	72.5	0.30	23.90	65	73
September 20	67.8	0.44	4.43	71	85
October 7	65.0	1.33	4.08	42	62
November 15	26.6	0.50	4.27	69	83
December 5	49.3	1.03	4.11	60	68
December 14	54.6	1.02	4.22	50	68

The broadest particle size distribution, gauged from the average annual standard geometric deviation of 10.50, was measured at Denver; the narrowest distribution, shown by an average annual standard deviation of 5.22, occurred at Washington. In Cincinnati, Philadelphia, St. Louis, and Washington, the particle size distribution changed from a narrow dispersion of particles in the first quarter to a broader distribution in the second quarter, followed by a comparatively narrow distribution in the third quarter. Fourth-quarter results for the sites were variable. A somewhat similar pattern was also found in Denver. Measurements at Chicago, however, exhibited broadest distribution during the first quarter and narrowest distribution during the third quarter. Except for Chicago, the dispersion patterns could be explained, at least in part, by seasonal factors. That is, during the first quarter, the narrow distribution of particles reflected the homogeneity of aerosols emitted predominantly from heating sources in winter; during the second quarter, the broadening of the particle distribution reflects the reduction of heating activity that removes a fraction of the large aerosol particles giving, effectively, a greater heterogeneity of aerosol particles; during the third quarter, the particle size distribution again becomes more narrowly dispersed with the influx of large dust and debris particles reentrained from the ground during dry, windy conditions.

Table 4. SIZE DISTRIBUTION MEASUREMENTS, DENVER, COLORADO

Sampling date, 1970	Concentration, $\mu g/m^3$	Mass median diameter, μ	Standard geometric deviation	% Particle mass $\leq 1\ \mu$	% Particle mass $\leq 2\ \mu$
January 29	25.8	0.49	7.18	65	77
February 14	73.7	0.23	15.53	70	79
February 26	47.9	0.45	8.09	65	77
March 9	59.7	0.55	5.01	65	79
April 19	58.3	0.18	11.14	76	84
May 7	49.7	0.17	12.49	76	83
May 23	50.7	0.25	7.41	76	85
June 2	50.6	0.16	12.19	77	85
June 16	47.5	0.19	8.86	77	86
July 3	54.9	0.20	10.37	76	84
July 23	77.1	0.37	9.13	67	78
July 30	49.2	0.17	9.72	78	86
August 10	78.1	0.74	6.90	57	70
August 23	48.6	0.30	6.37	75	85
September 11	70.8	0.60	6.86	61	74
September 27	38.1	0.05	75.21	76	81
October 7	15.6	1.53	7.98	42	55
October 20	25.4	1.51	25.35	54	54
November 5	81.3	0.47	11.35	62	73
November 15	64.3	0.63	11.98	58	68
December 14	188.3	1.44	8.23	44	57

Composite values for the average percent of the particle mass ⩽ 1 micron in diameter and the average percent ⩽ 2 microns in diameter are also shown in Table 8. Because these values were interpolated directly from the particle size distribution curves, they provide a more accurate picture of the particle size than does the mass median diameter, a value often obtained by extrapolating the distribution curve. On a yearly-average basis, Denver, Philadelphia, and Washington exhibited approximately the same percentages of particulate mass ⩽ 1 micron in diameter, ranging from 65 to 68 percent. Chicago and St. Louis exhibited the lowest proportions, 55 percent and 54 percent respectively; Cincinnati showed an intermediate value of 59 percent. Chicago, Denver, St. Louis, and Washington exhibited similar quarterly composite patterns in that the average percentage of particle mass ⩽ 1 micron in diameter increased in the second quarter, but then decreased during the third and fourth quarters. Cincinnati and Philadelphia both exhibited a continually decreasing percentage of particulate mass ⩽ 1 micron in diameter from the first through the fourth quarter. The same quarterly composite trends for the percent particle mass ⩽ 1 micron in diameter were also found for the particle mass ⩽ 2 microns in diameter. At Chicago, Philadelphia, and Washington, however, the percent

Table 5. SIZE DISTRIBUTION MEASUREMENTS, PHILADELPHIA, PENNSYLVANIA

Sampling date, 1970	Concentration, $\mu g/m^3$	Mass median diameter, μ	Standard geometric deviation	% Particle mass $\leqslant 1\ \mu$	% Particle mass $\leqslant 2\ \mu$
March 10	51.8	0.44	8.44	65	76
March 22	69.0	0.28	4.14	81	92
April 7	63.7	0.29	7.33	74	84
April 19	47.8	0.24	7.55	76	85
May 7	43.9	0.12	9.81	83	89
May 27	53.6	0.42	0.44	65	76
June 2	56.2	0.42	17.32	62	71
June 14	40.0	0.20	22.41	70	77
July 4	67.0	0.82	2.91	58	80
July 14	57.4	0.39	6.20	70	82
July 30	86.0	0.90	2.97	54	77
August 10	86.8	0.88	3.19	55	76
September 11	53.9	0.25	7.20	76	86
September 27	42.1	0.23	5.21	82	91
September 30	69.6	0.53	4.47	67	82
October 7	85.4	0.02	12.92	93	96
October 21	41.7	1.41	4.41	41	60
November 10	77.8	1.62	3.68	36	57
November 17	47.6	0.83	3.63	56	76
December 5	25.9	0.62	4.66	63	78

particle mass ⩽ 2 microns in diameter was approximately the same in the second and in the third quarters.

The network described here was expanded by four additional stations in January 1971 to make a total of 10 cascade impactor stations. Two additional urban stations were installed at Steubenville, Ohio, and Seattle, Washington; two background stations were located at Grand Canyon, Colorado, and Cape Hatteras, North Carolina, to provide particle size information on nonurban aerosols. Plans are to develop a network of about 50 sampling stations by 1974 to determine the particle size distribution of suspended matter in the atmosphere. The collected samples will be subject to detailed chemical analysis for hazardous and biologically active elements and compounds. This network will provide data to identify pollutants in the respirable size range and provide some indication as to the depth of penetration in the respiratory system.

Table 6. SIZE DISTRIBUTION MEASUREMENTS, ST. LOUIS, MISSOURI

Sampling date, 1970	Concentration, $\mu g/m^3$	Mass median diameter μ	Standard geometric deviation	% Particle mass $\leq 1\ \mu$	% Particle mass $\leq 2\ \mu$
January 13	173.9	1.22	5.92	46	61
January 29	29.2	1.04	3.43	49	70
February 14	75.0	0.66	6.09	60	75
February 25	46.8	0.29	14.96	68	76
March 9	81.6	1.34	9.44	45	58
April 8	67.9	0.94	7.86	52	65
April 19	52.6	0.21	7.81	78	87
May 7	90.0	0.43	18.27	62	70
May 27	78.7	0.40	19.04	62	71
June 16	81.0	0.78	5.33	56	71
July 4	18.1	0.40	10.34	65	76
July 14	68.1	1.09	4.53	48	66
July 30	66.5	0.89	8.99	53	65
August 10	36.8	1.05	4.66	49	66
August 20	85.8	0.74	6.26	57	81
August 22	72.4	0.48	9.23	63	74
August 25	89.9	0.88	5.84	53	68
August 27	123.8	1.21	4.26	45	64
September 16	79.7	0.77	4.91	57	73
November 15	23.4	0.40	4.94	72	84
December 5	23.4	0.40	4.48	51	69
December 14	68.3	1.47	5.36	41	58

Table 7. SIZE DISTRIBUTION MEASUREMENTS, WASHINGTON, D.C.

Sampling date, 1970	Concentration $\mu g/m^3$	Mass median diameter μ	Standard geometric deviation	% Particle mass $\leq 1\ \mu$	% Particle mass $\leq 2\ \mu$
January 29	67.2	0.70	7.66	57	70
February 14	46.0	0.45	4.25	71	85
February 25	48.5	0.63	7.43	59	72
March 10	44.6	0.33	10.73	68	78
March 22	59.6	0.39	3.31	78	91
April 8	64.7	0.52	3.59	70	86
April 19	47.6	0.24	4.54	83	92
May 7	48.3	0.07	9.33	88	94
June 1	54.1	0.12	44.79	71	77
June 3	49.4	0.17	10.37	77	85
June 16	67.3	0.53	16.96	59	68
July 4	68.9	0.54	2.81	73	90
July 15	87.5	0.64	3.39	65	83
July 30	81.5	0.62	3.54	65	82
August 11	73.6	0.40	4.46	73	86
September 11	59.0	0.23	10.88	73	82
September 20	69.1	0.49	4.24	69	84
October 7	48.9	0.87	3.12	55	77
October 20	43.9	1.20	4.48	46	64
November 7	72.4	0.70	4.15	60	77
November 15	19.6	0.26	4.33	82	92
December 5	37.6	0.50	4.05	69	84
December 15	21.7	0.98	3.83	51	71

Table 8. QUARTERLY AND ANNUAL SIZE DISTRIBUTION COMPOSITES, 1970

City and collection period	Number of samples	Average concentration, $\mu g/m^3$	Average mass median diameter, μ	Average standard geometric deviation	Average % particle mass $\leq 1\ \mu$	Average % particle mass $\leq 2\ \mu$
Chicago						
1	4	97.8	2.31	10.41	37	48
2	6	82.4	0.51	8.16	63	74
3	7	98.3	0.62	5.88	61	75
4	4	63.0	0.66	8.00	58	71
Annual	21	86.5	0.76	8.18	55	68
Cincinnati						
1	1	61.9	0.37	5.71	72	84
2	6	77.5	0.54	6.47	63	76
3	7	88.9	0.77	5.15	57	72
4	4	48.6	1.01	4.32	50	68
Annual	18	74.3	0.70	5.49	59	74
Denver						
1	4	51.4	0.41	7.99	67	78
2	5	51.4	0.19	10.22	76	85
3	7	59.1	0.34	9.50	69	79
4	5	80.7	1.02	10.65	50	62
Annual	21	59.7	0.40	10.50	65	75
Philadelphia						
1	2	60.4	0.31	6.02	74	85
2	6	50.9	0.26	11.21	71	80
3	7	66.1	0.62	3.91	64	81
4	5	56.8	0.55	6.34	63	76
Annual	20	58.5	0.47	5.65	67	80
St. Louis						
1	5	81.2	0.97	6.61	51	65
2	5	73.7	0.53	10.33	61	72
3	9	76.5	0.89	5.69	53	68
4	3	44.5	1.02	5.34	50	66
Annual	22	73.1	0.83	6.80	54	68
Washington						
1	5	53.0	0.47	5.98	67	79
2	6	55.3	0.26	8.80	73	83
3	6	73.5	0.51	3.95	69	84
4	6	41.1	0.73	4.11	59	76
Annual	23	56.3	0.46	5.22	68	81

SUMMARY

A successful method of determining particle size distributions of suspended particulate matter in a routine field operation has been demonstrated. Gravimetric determination of particulate matter, fractionated by virtue of the aerodynamic dimension of the particles, indicated that at six major urban areas in the United States suspended particulate matter is predominantly submicron in size. Trends in particulate concentrations and particle size distributions appear to be influenced at least in part by seasonal and by emission source factors.

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APPENDIX A
SIZE DISTRIBUTION CURVES, 1970 QUARTERLY COMPOSITES AND AVERAGES

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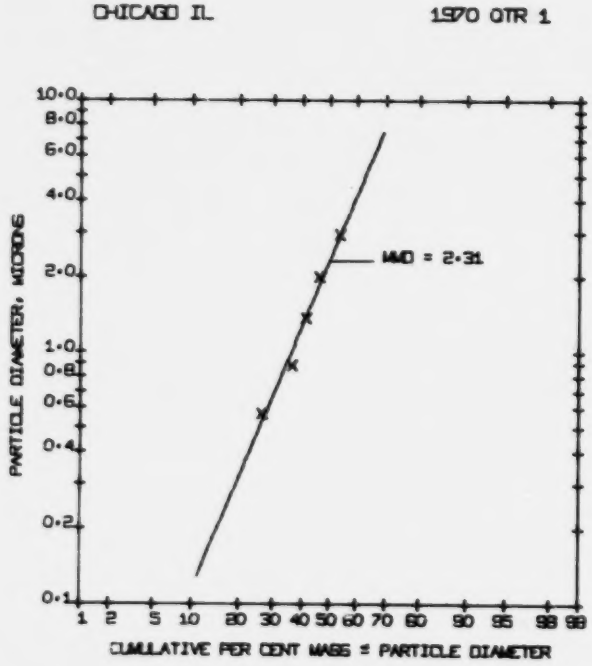

Figure A-1. Composite size distribution curve, Chicago, first quarter, 1970.

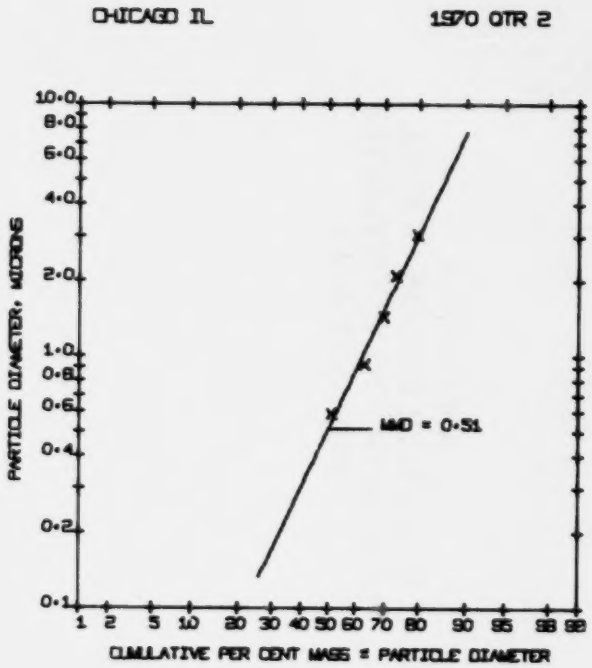

Figure A-2. Composite size distribution curve, Chicago, second quarter, 1970.

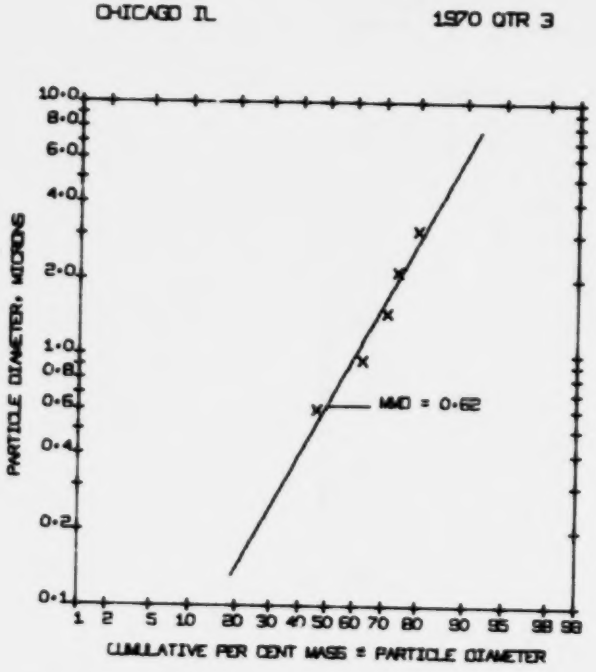

Figure A-3. Composite size distribution curve, Chicago, third quarter, 1970.

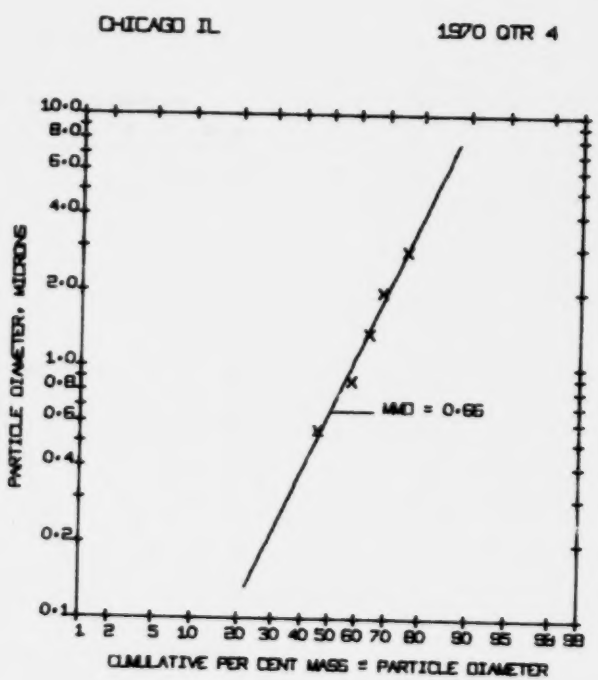

Figure A-4. Composite size distribution curve, Chicago, fourth quarter, 1970.

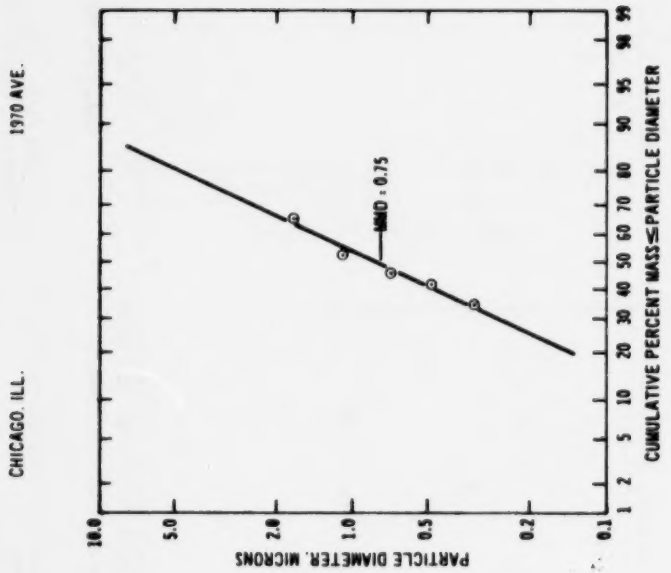

Figure A-5. Composite size distribution curve, Chicago, 1970 average.

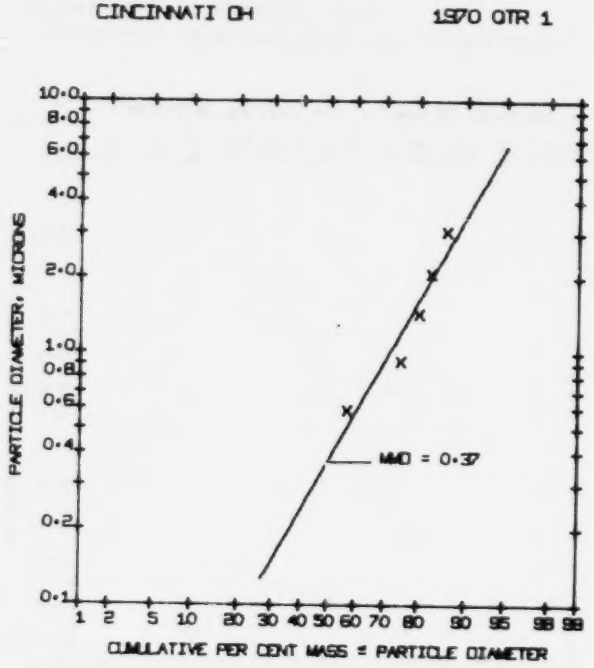

Figure A-6. Composite size distribution curve, Cincinnati, first quarter, 1970.

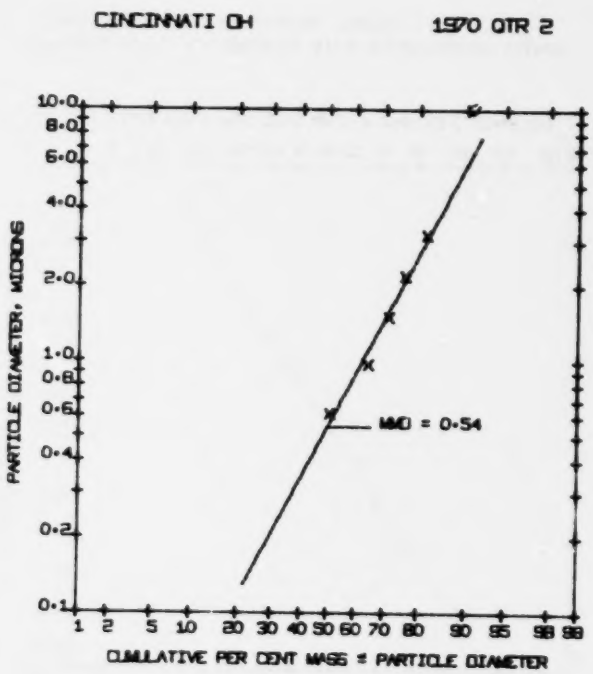

Figure A-7. Composite size distribution curve, Cincinnati, second quarter, 1970.

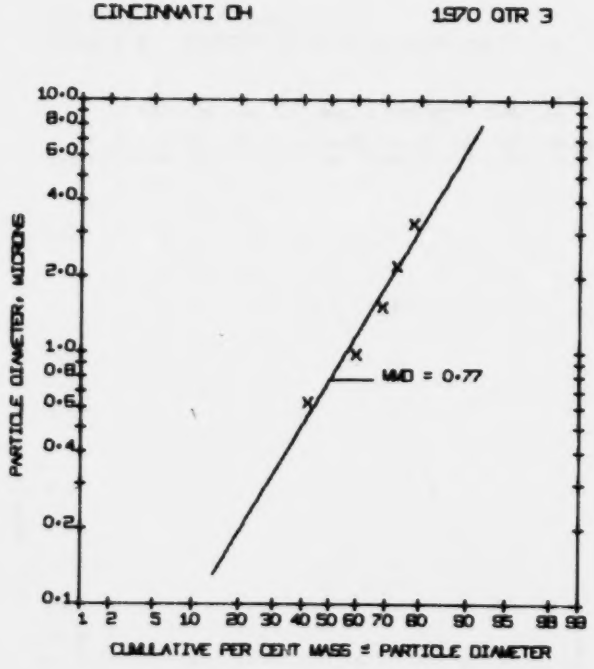

Figure A-8. Composite size distribution curve, Cincinnati, third quarter, 1970.

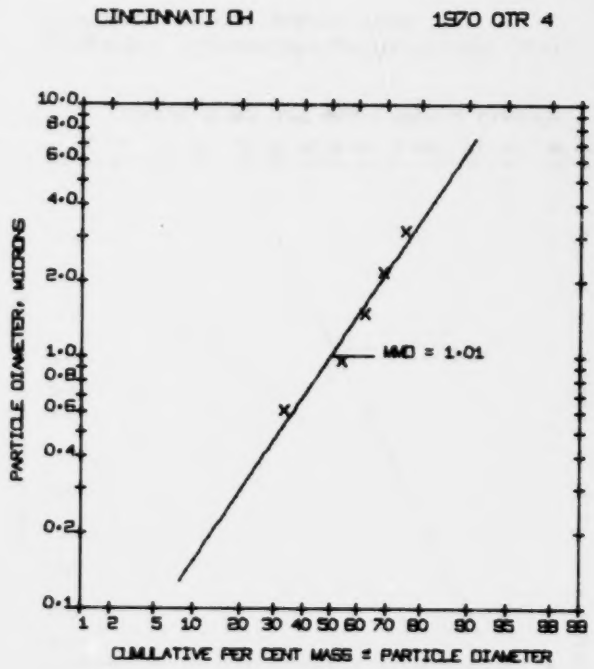

Figure A-9. Composite size distribution curve, Cincinnati, fourth quarter, 1970.

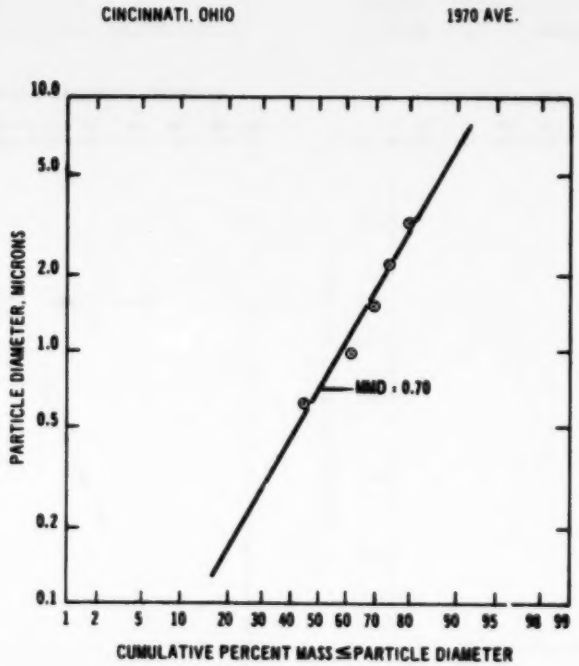

Figure A-10. Composite size distribution curve, Cincinnati, 1970 average.

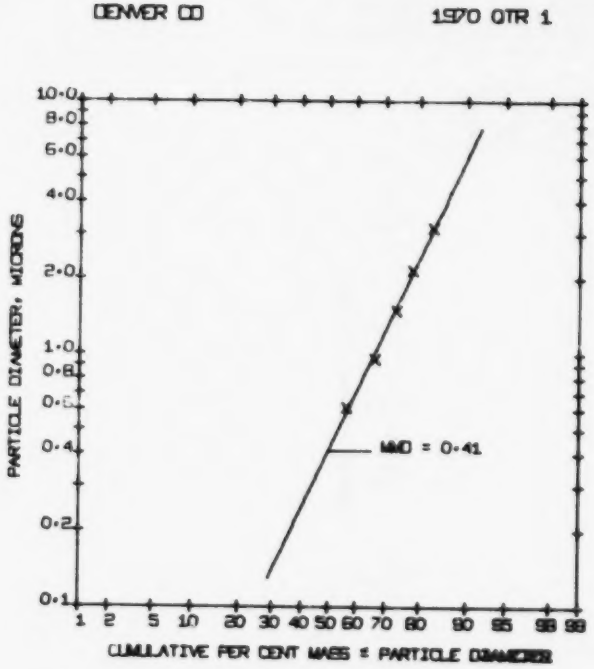

Figure A-11. Composite size distribution curve, Denver, first quarter, 1970.

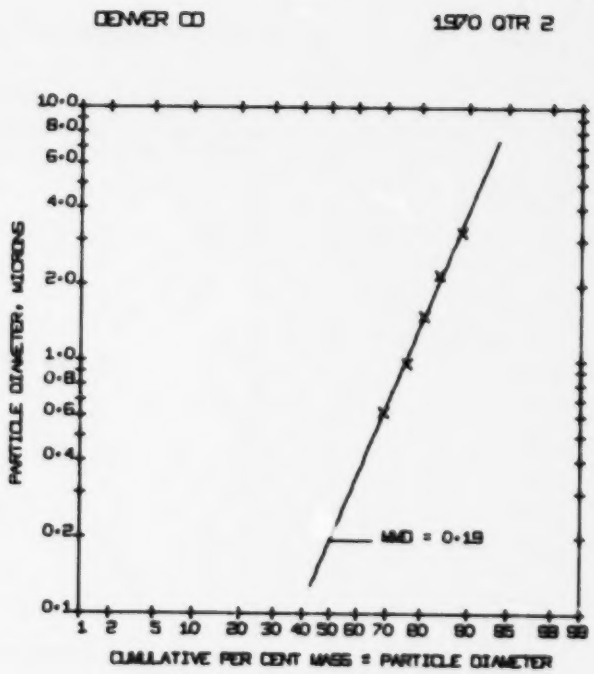

Figure A-12. Composite size distribution curve, Denver, second quarter, 1970.

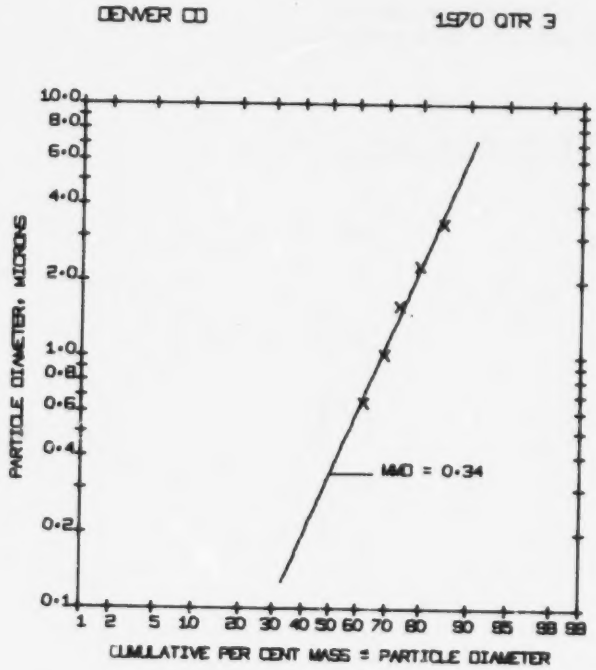

Figure A-13. Composite size distribution curve, Denver, third quarter, 1970.

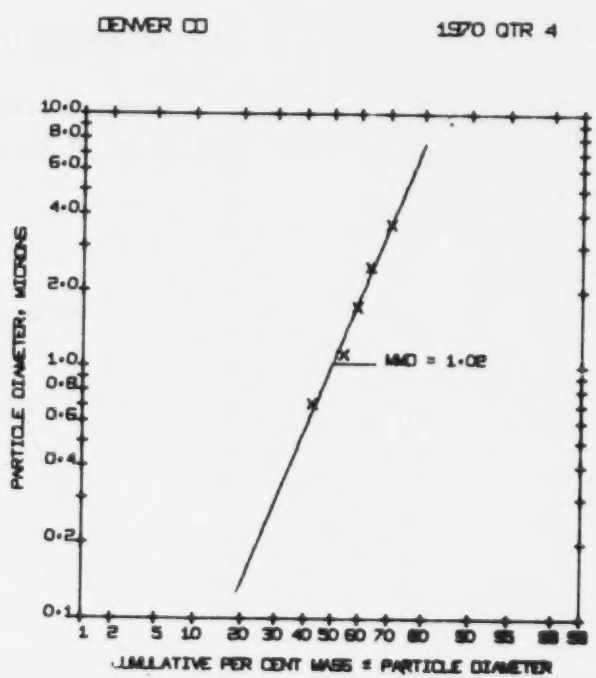

Figure A-14. Composite size distribution curve, Denver, fourth quarter, 1970.

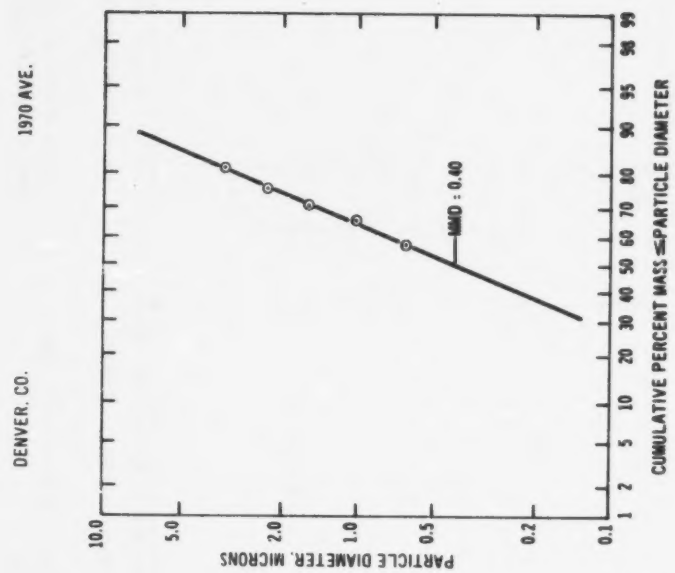

Figure A-15. Composite size distribution curve, Denver, 1970 average.

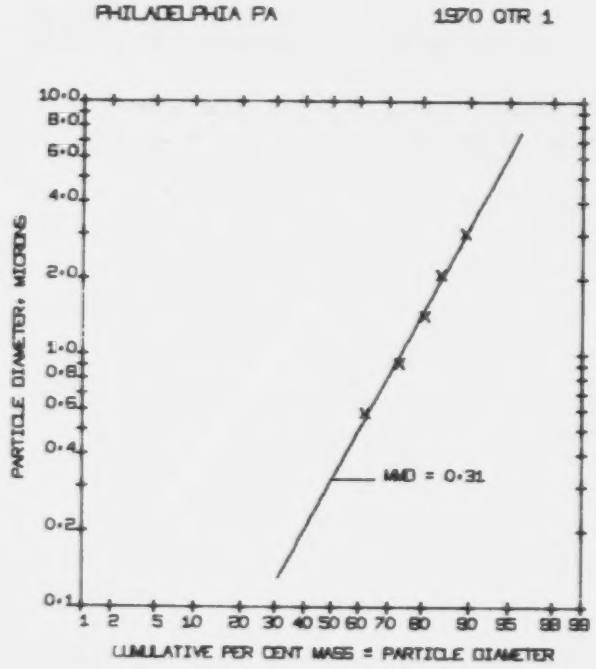

Figure A-16. Composite size distribution curve, Philadelphia, first quarter, 1970.

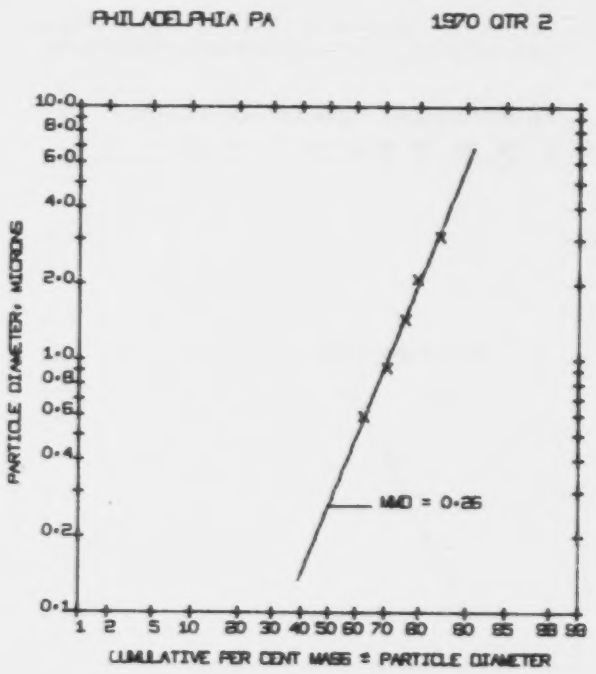

Figure A-17. Composite size distribution curve, Philadelphia, second quarter, 1970.

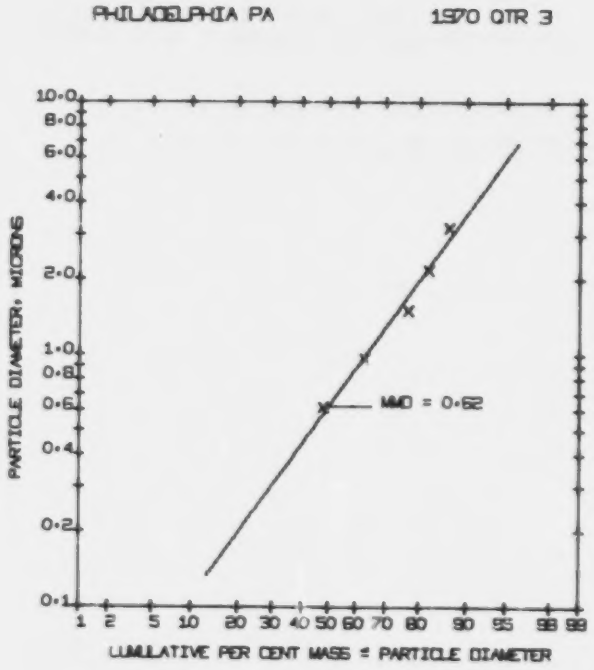

Figure A-18. Composite size distribution curve, Philadelphia, third quarter, 1970.

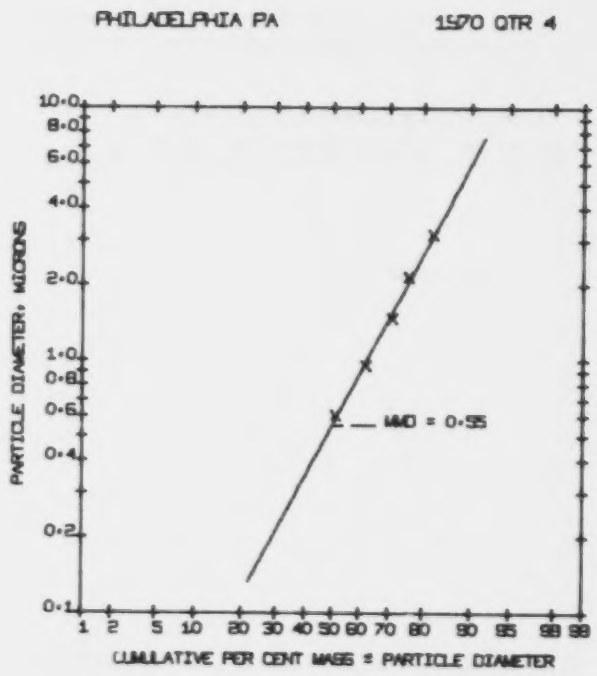

Figure A-19. Composite size distribution curve, Philadelphia, fourth quarter, 1970.

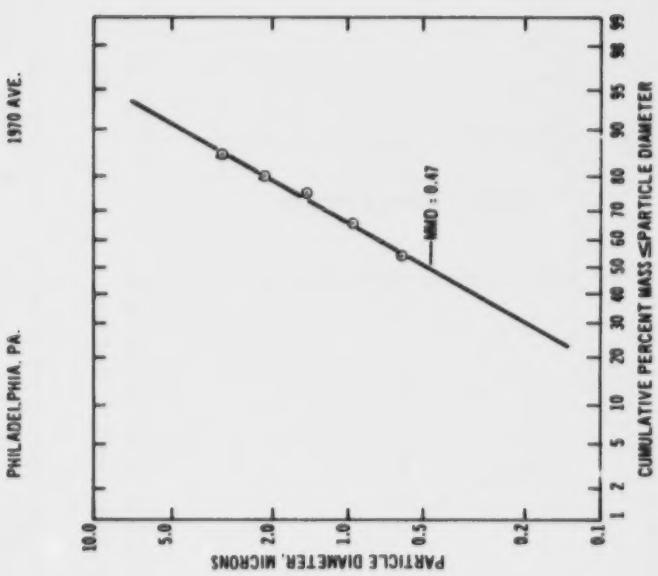

Figure A-20. Composite size distribution curve, Philadelphia, 1970 average.

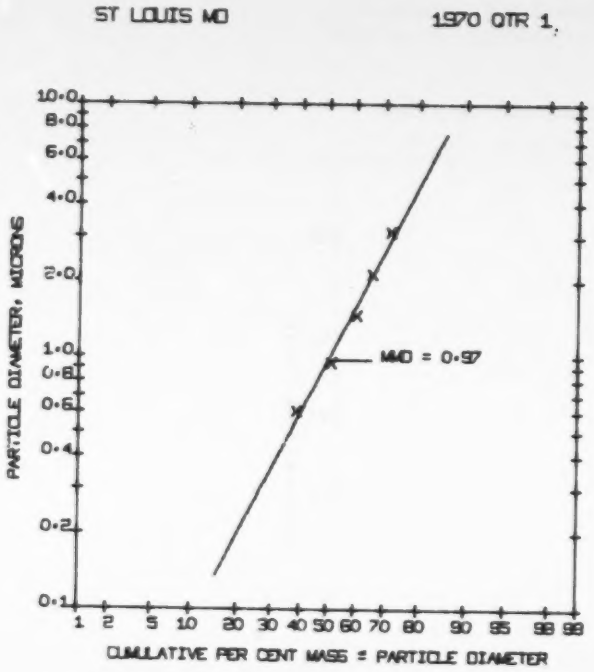

Figure A-21. Composite size distribution curve, St. Louis, first quarter, 1970.

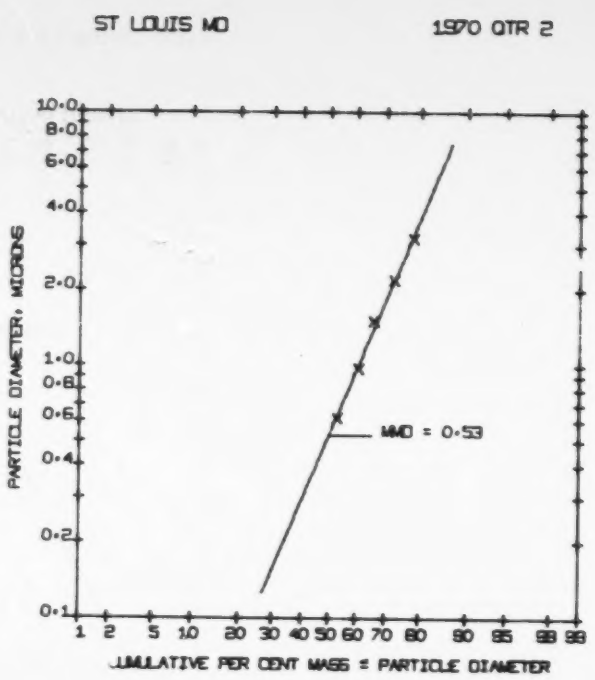

Figure A-22. Composite size distribution curve, St. Louis, second quarter, 1970.

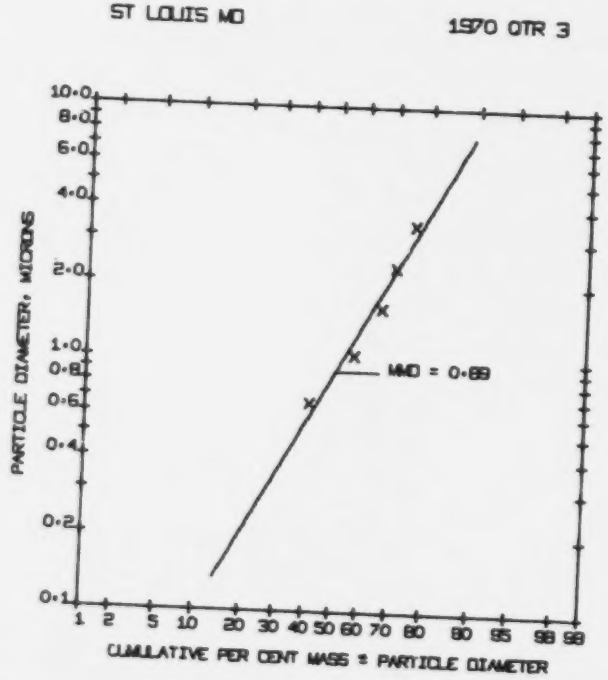

Figure A-23. Composite size distribution curve, St. Louis, third quarter. 1970.

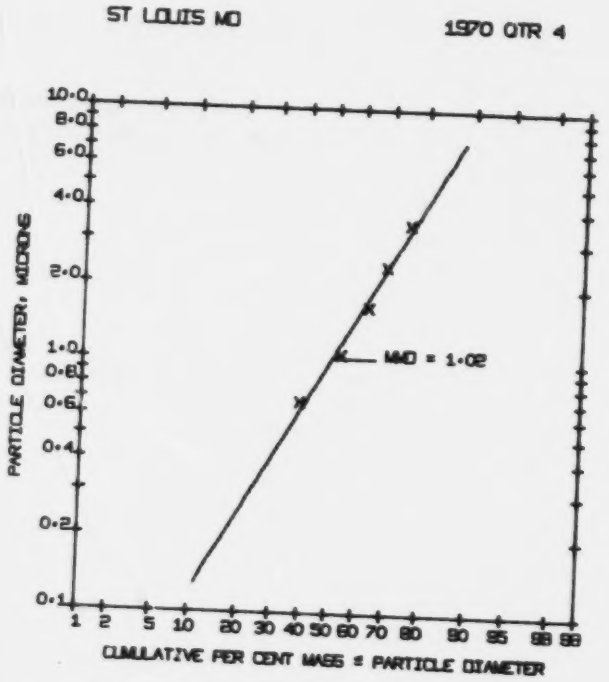

Figure A-24. Composite size distribution curve, St. Louis, fourth quarter, 1970.

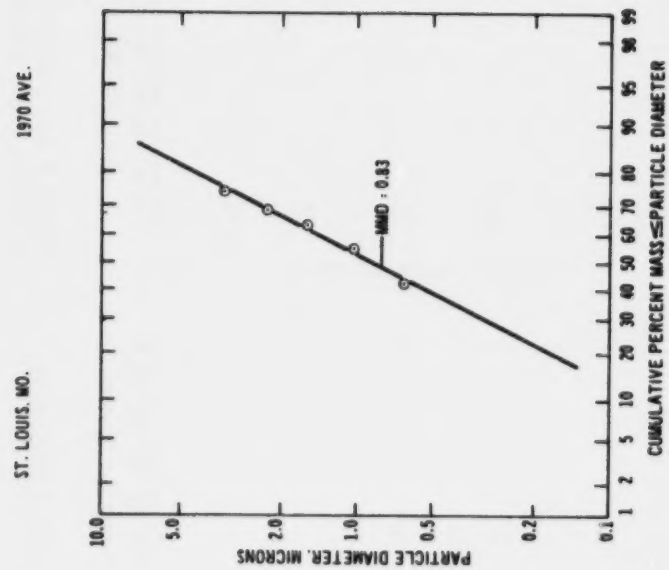

Figure A-25. Composite size distribution curve, St. Louis, 1970 average.

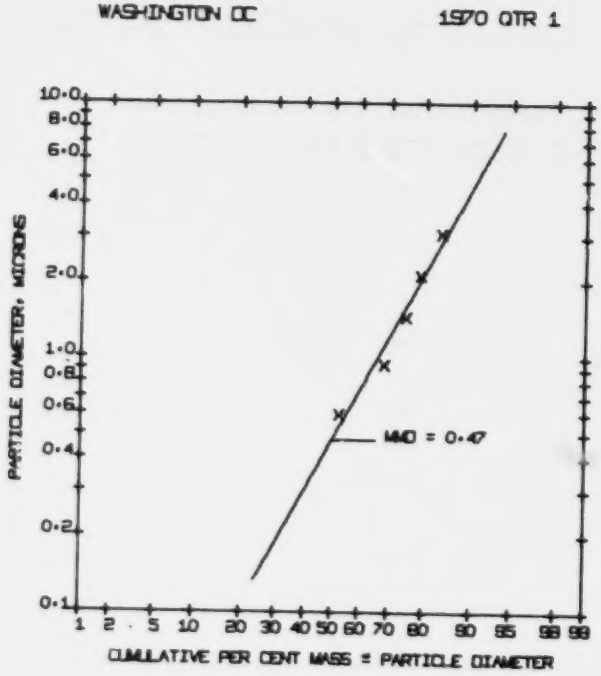

Figure A-26. Composite size distribution curve, Washington, D.C., first quarter, 1970.

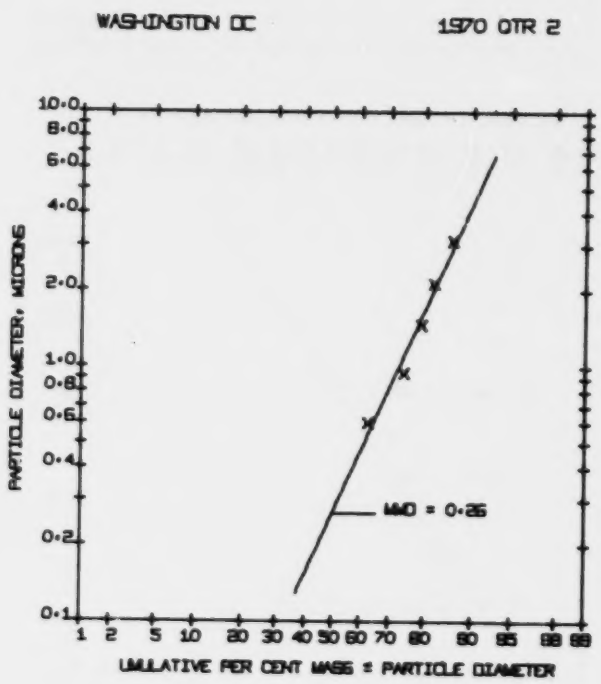

Figure A-27. Composite size distribution curve, Washington, D.C., second quarter, 1970.

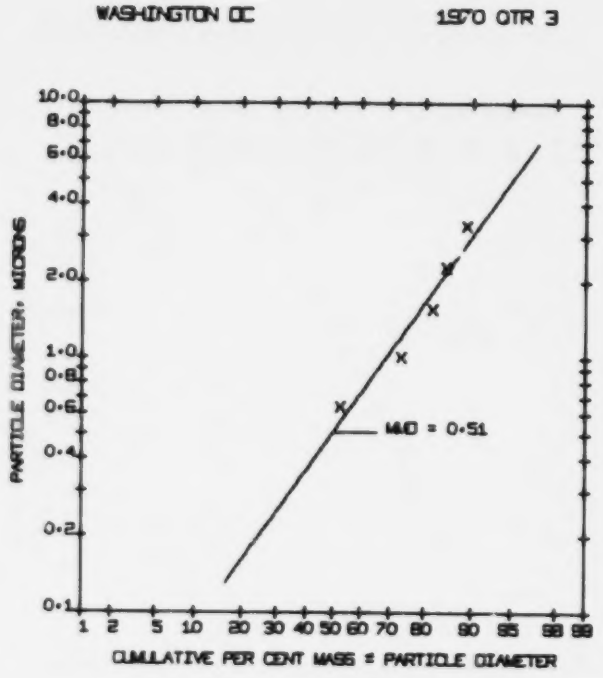

Figure A-28. Composite size distribution curve, Washington, D.C., third quarter, 1970.

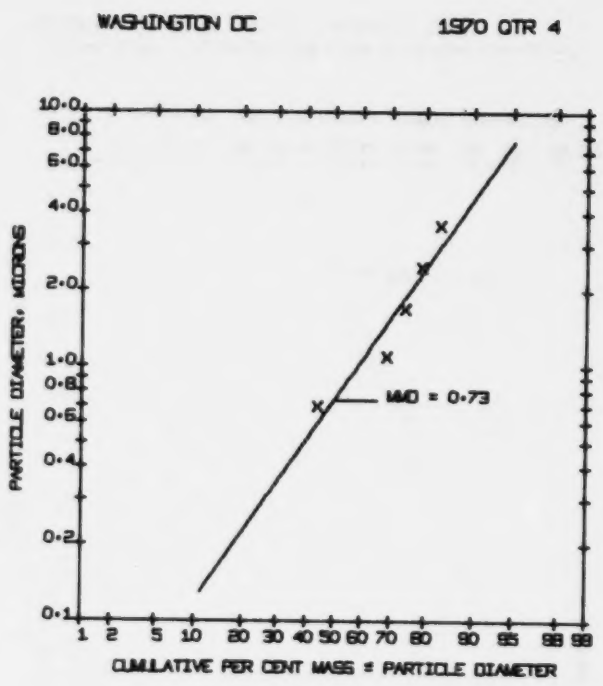

Figure A-29. Composite size distribution curve, Washington, D.C., fourth quarter, 1970.

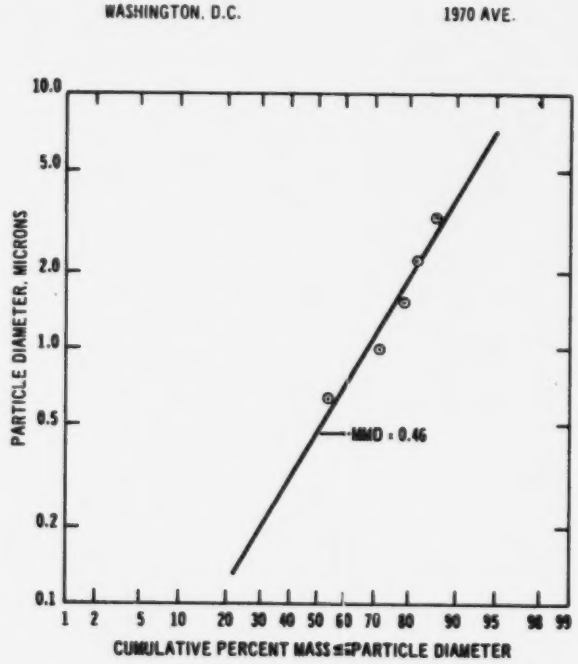

Figure A-30. Composite size distribution curve, Washington, D.C., 1970 average.

APPENDIX B
DAILY PARTICLE SIZE DISTRIBUTION CURVES, CHICAGO, ILLINOIS

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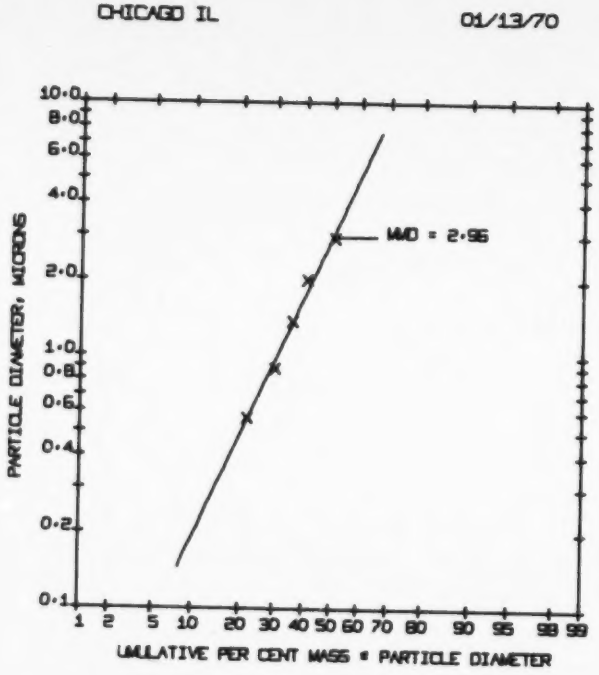

Figure B-1. Particle size distribution curve, Chicago, January 13, 1970.

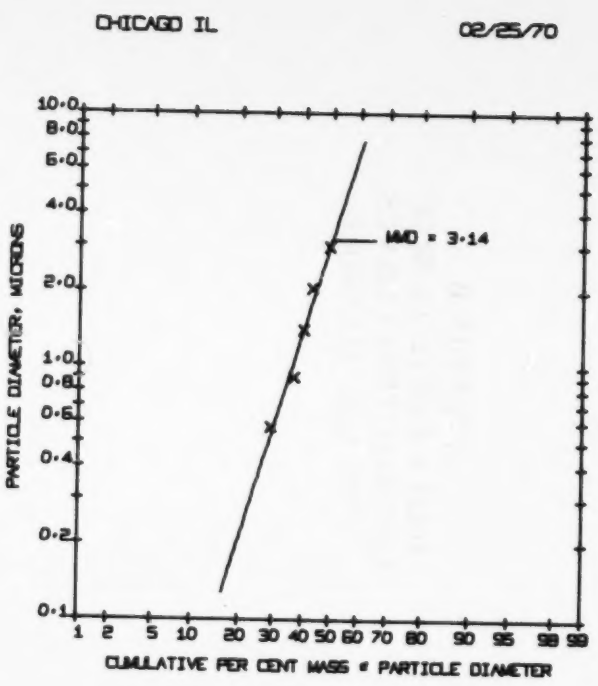

Figure B-2. Particle size distribution curve, Chicago, February 25, 1970.

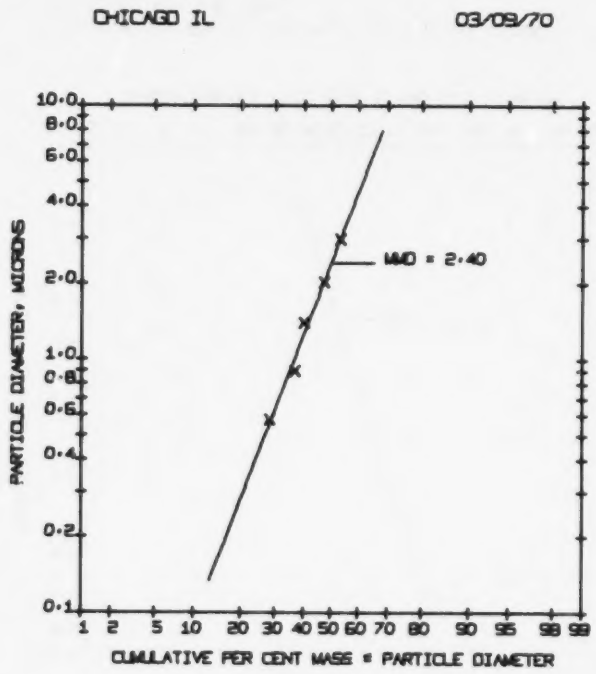

Figure B-3. Particle size distribution curve, Chicago, March 9, 1970.

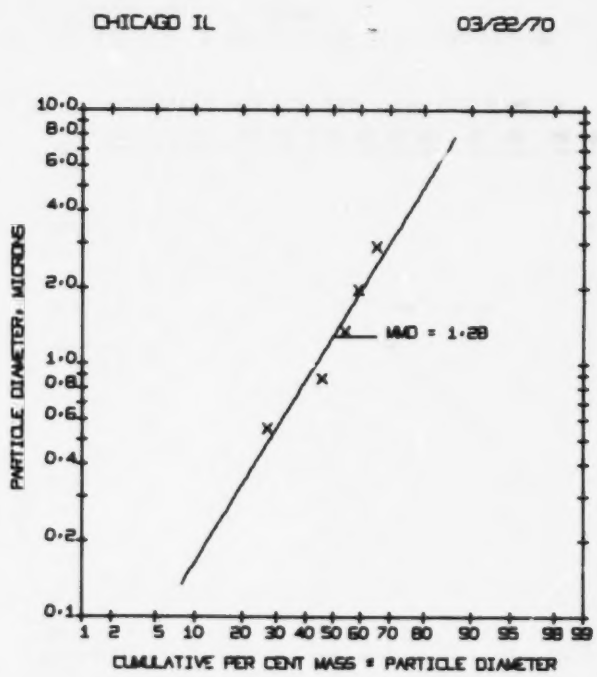

Figure B-4. Particle size distribution curve, Chicago, March 22, 1970.

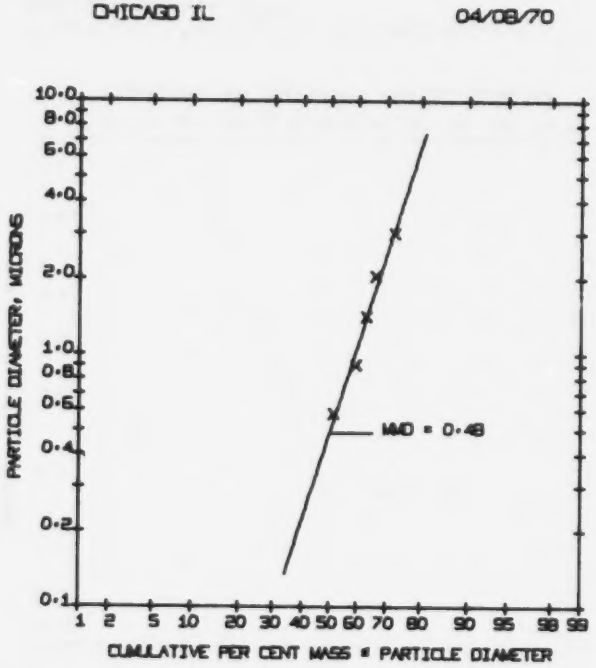

Figure B-5. Particle size distribution curve, Chicago, April 8, 1970.

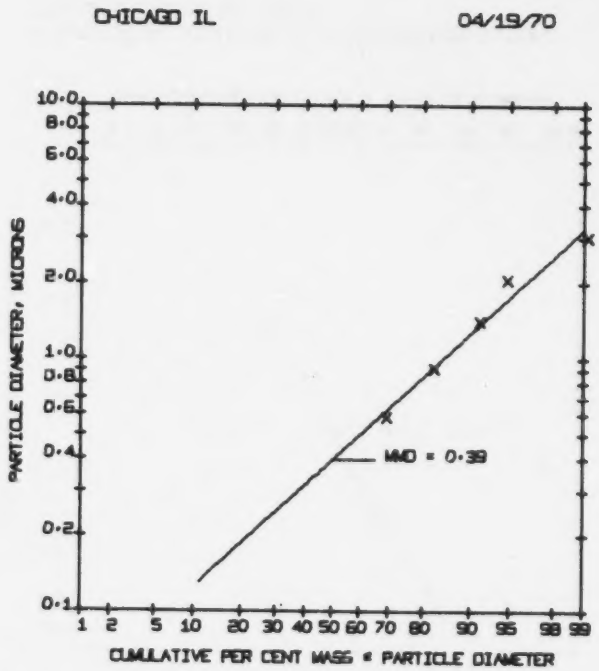

Figure B-6 Particle size distribution curve, Chicago, April 19, 1970.

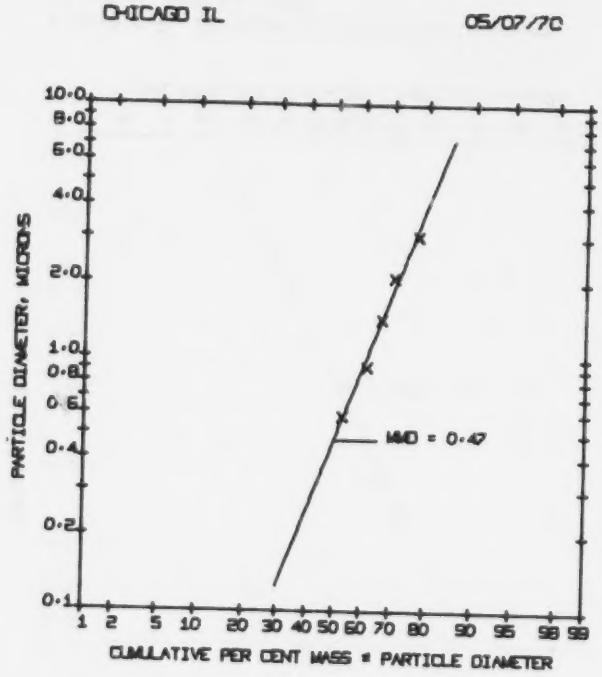

Figure B-7. Particle size distribution curve, Chicago, May 7, 1970.

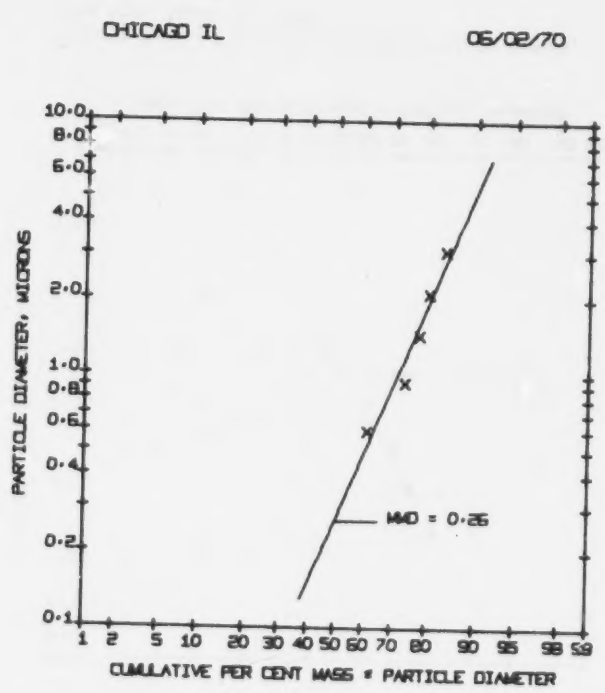

Figure B-8. Particle size distribution curve, Chicago, June 2, 1970.

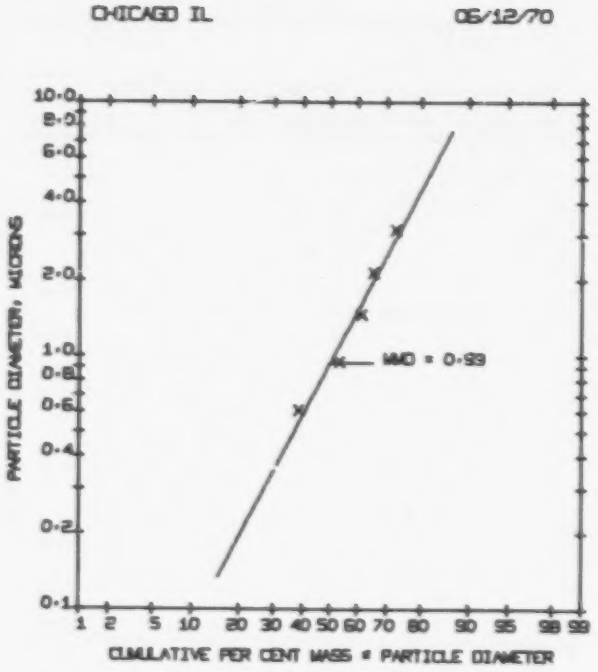

Figure B-9. Particle size distribution curve, Chicago, June 12, 1970.

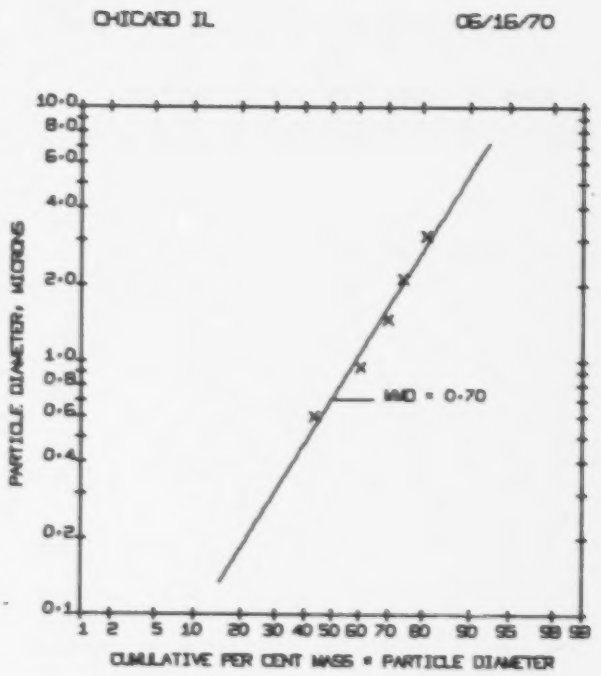

Figure B-10. Particle size distribution curve, Chicago, June 16, 1970.

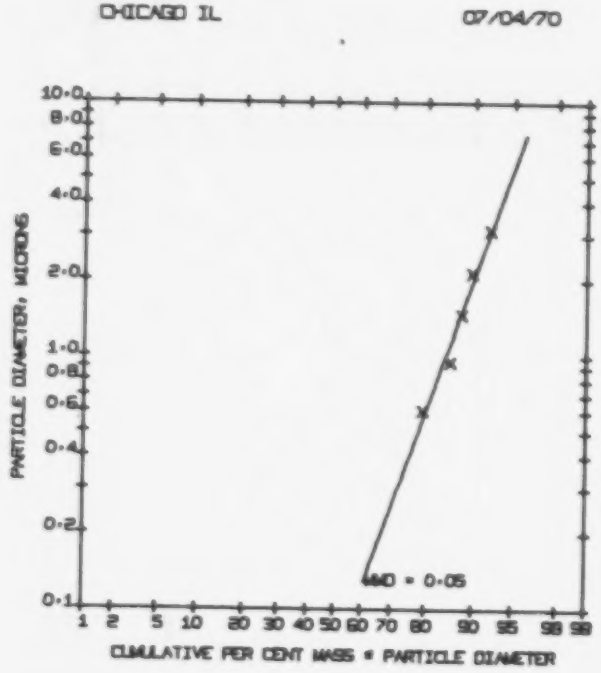

Figure B-11. Particle size distribution curve, Chicago, July 4, 1970.

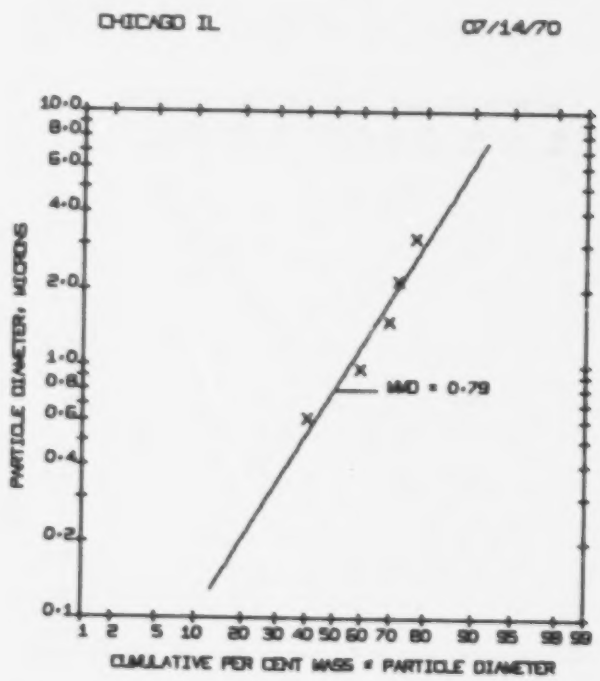

Figure B-12. Particle size distribution curve, Chicago, July 14, 1970.

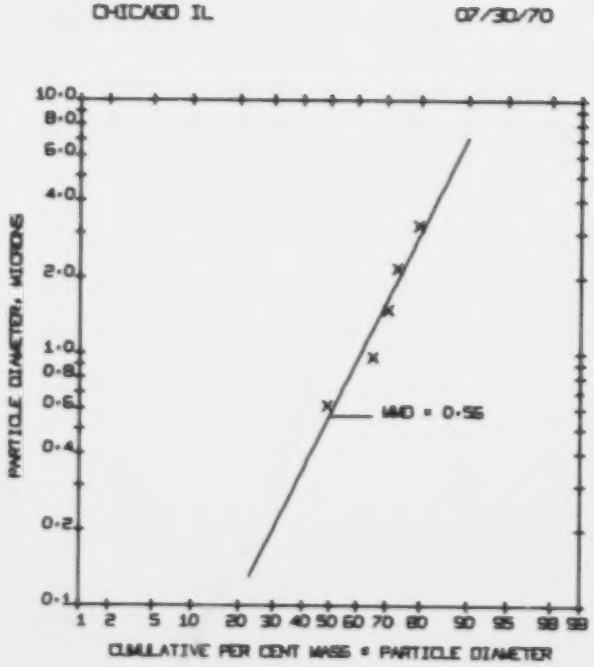

Figure B-13. Particle size distribution curve, Chicago, July 30, 1970.

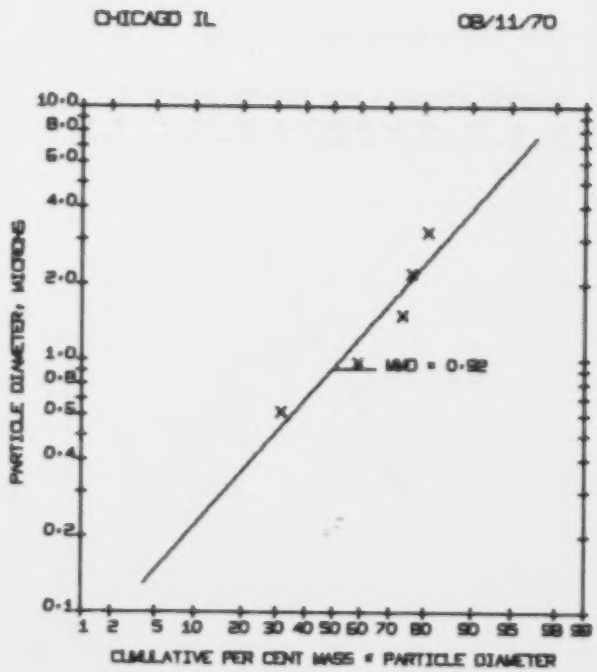

Figure B-14. Particle size distribution curve, Chicago, August 11, 1970.

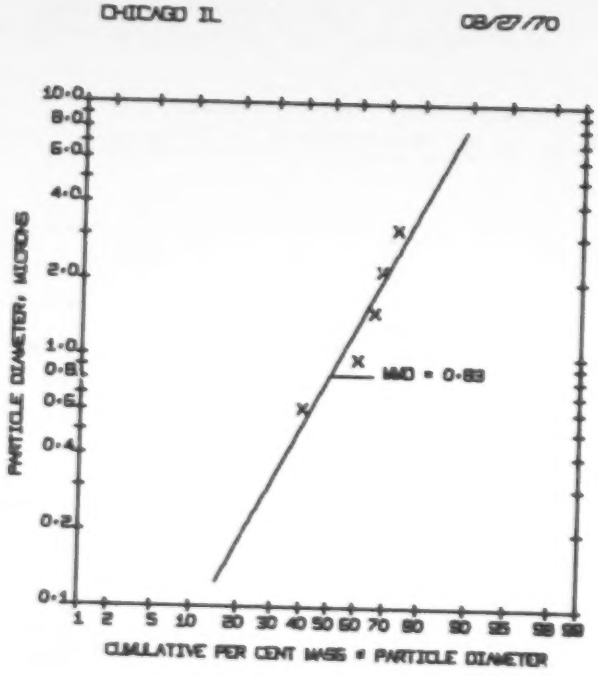

Figure B-15. Particle size distribution curve, Chicago, August 27, 1970.

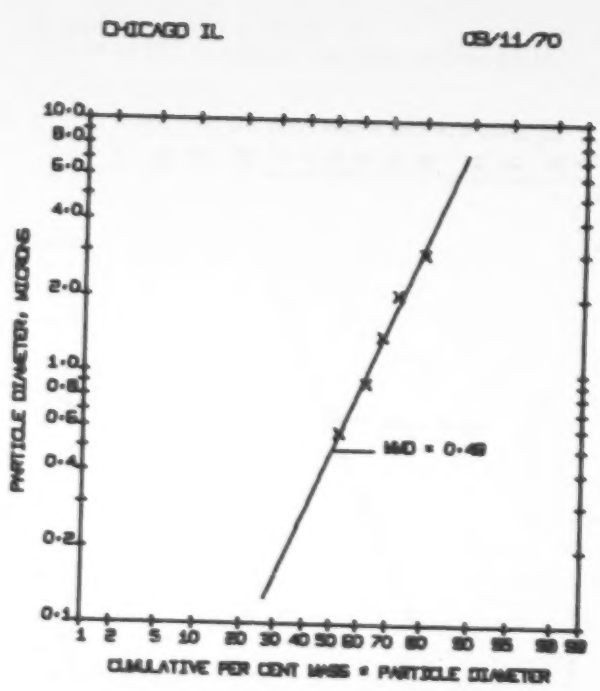

Figure B-16. Particle size distribution curve, Chicago, September 11, 1970.

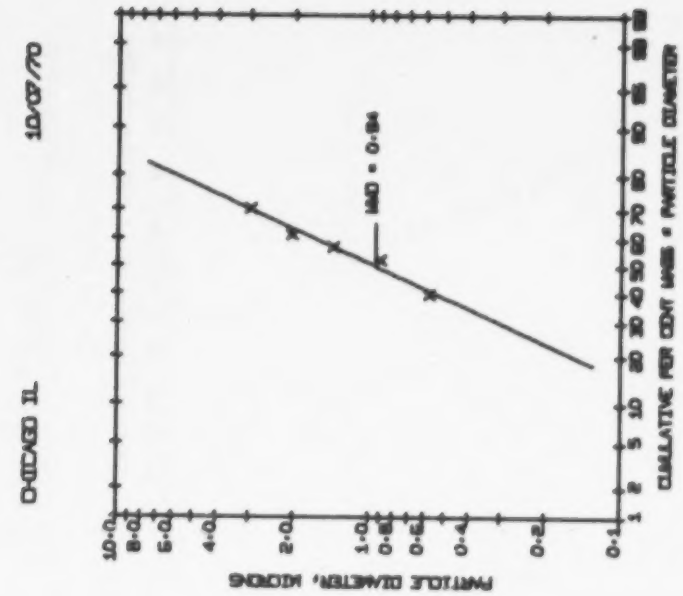

Figure B-17. Particle size distribution curve, Chicago, September 20, 1970.

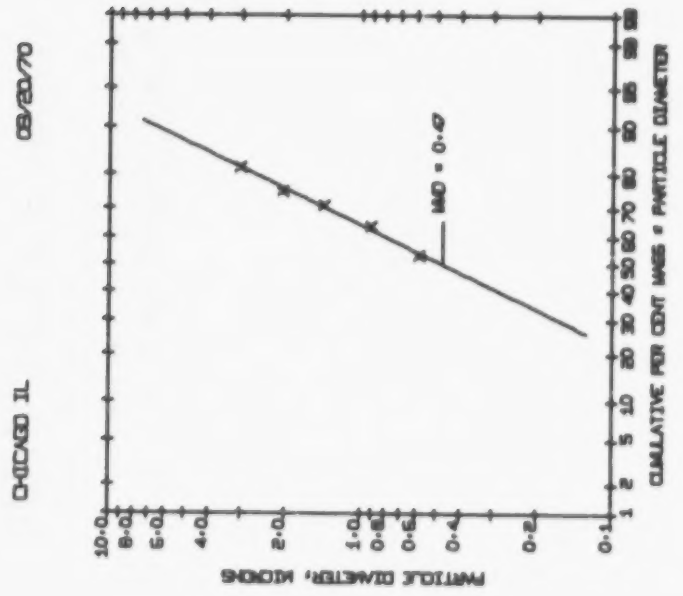

Figure B-18 . Particle size distribution curve, Chicago, October 7, 1970.

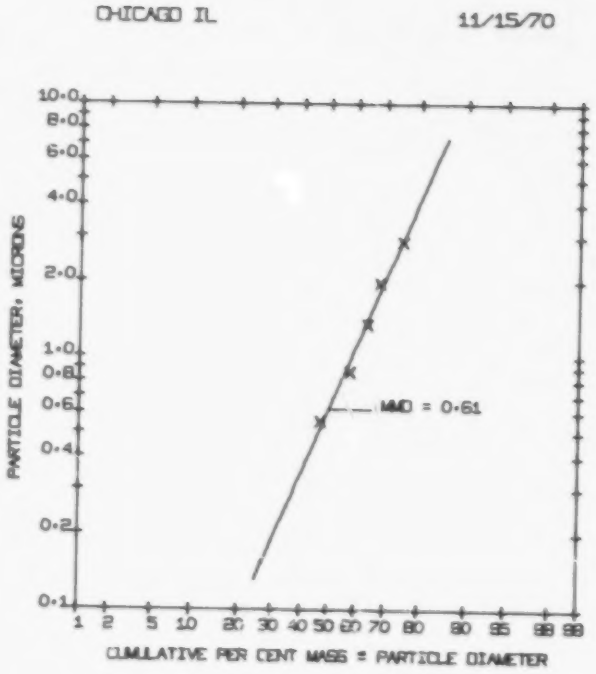

Figure B-19. Particle size distribution curve, Chicago, November 15, 1970.

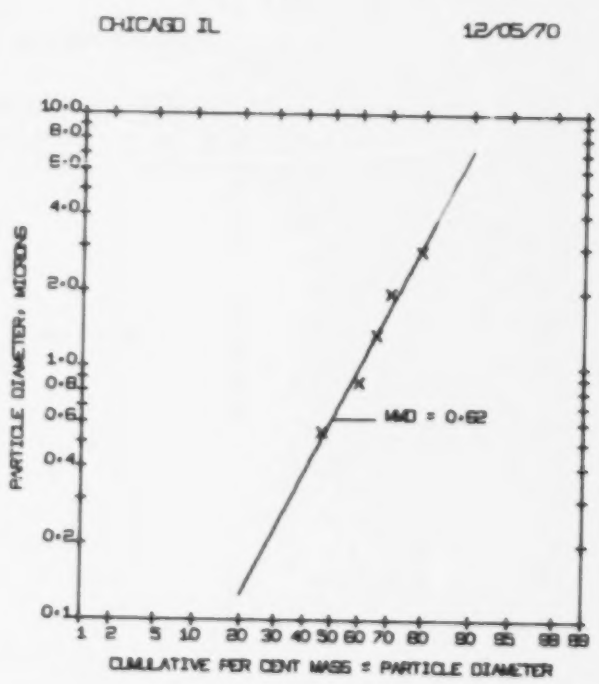

Figure B-20. Particle size distribution curve Chicago, December 5, 1970.

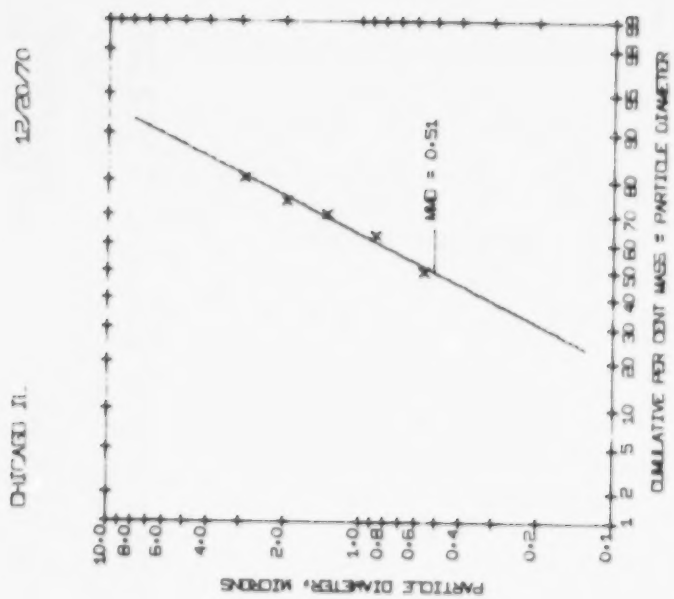

Figure B-21. Particle size distribution curve, Chicago, December 20, 1970.

APPENDIX C
DAILY PARTICLE SIZE DISTRIBUTION CURVES, CINCINNATI, OHIO

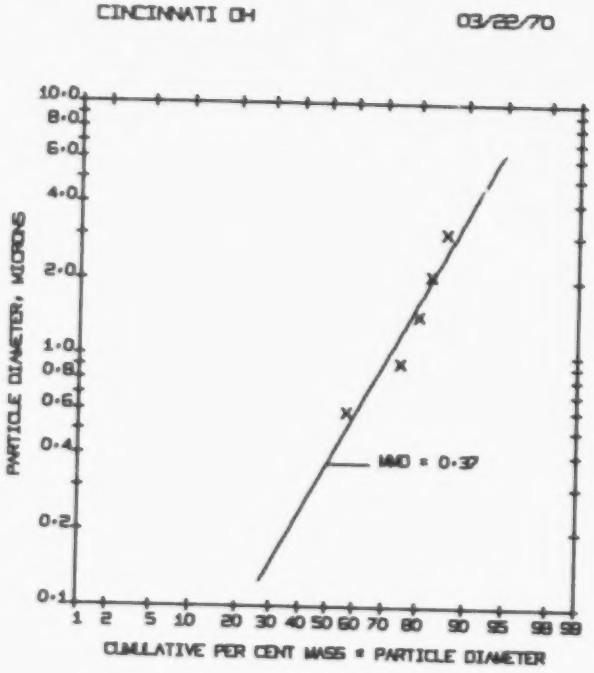

Figure C-1. Particle size distribution curve, Cincinnati, March 22, 1970.

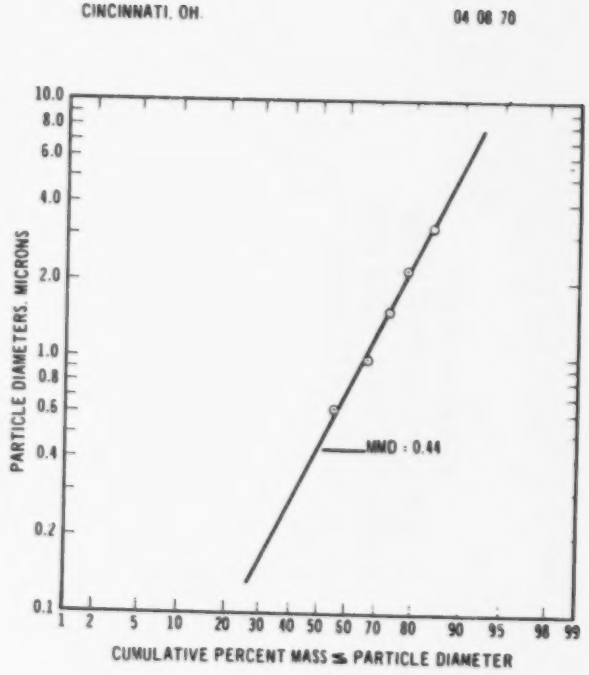

Figure C-2. Particle size distribution curve, Cincinnati, April 8, 1970.

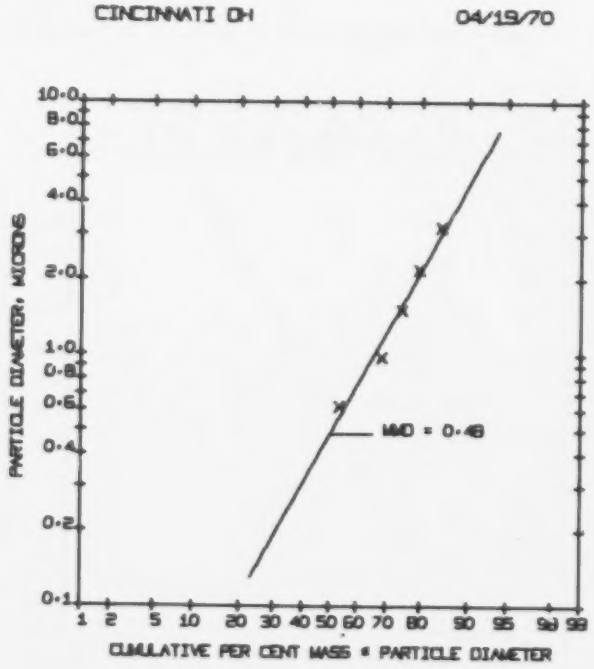

Figure C-3. Particle size distribution curve, Cincinnati, April 19, 1970.

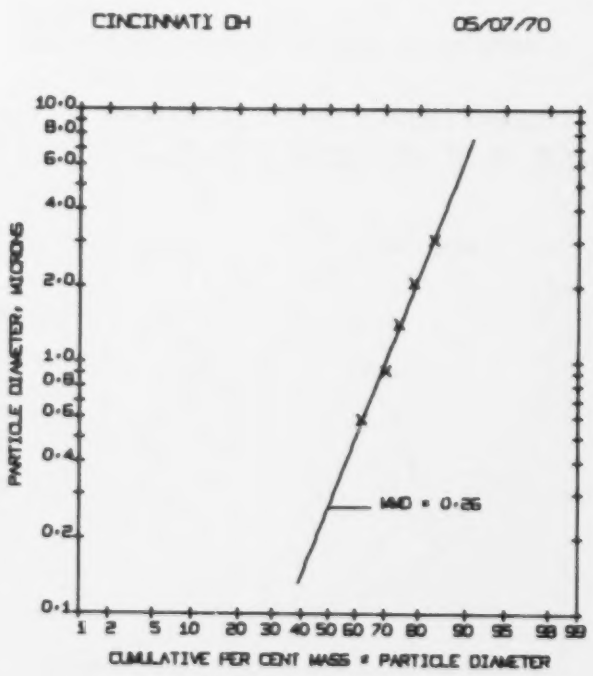

Figure C-4. Particle size distribution curve, Cincinnati, May 7, 1970.

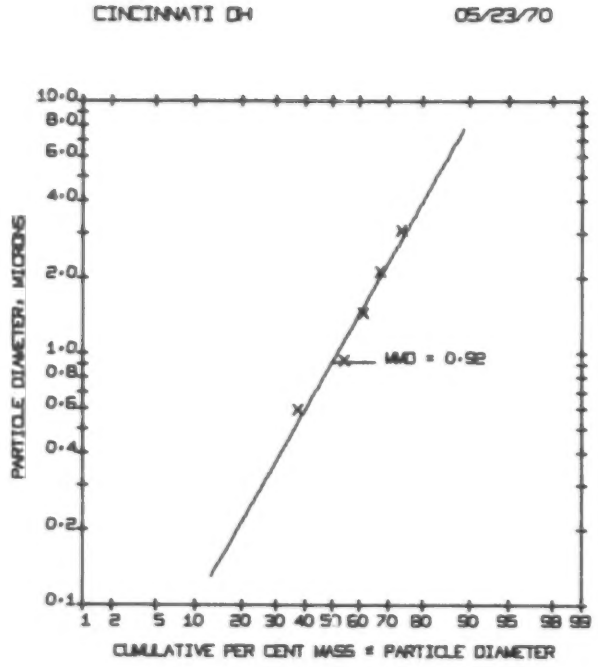

Figure C-5. Particle size distribution curve, Cincinnati, May 23, 1970.

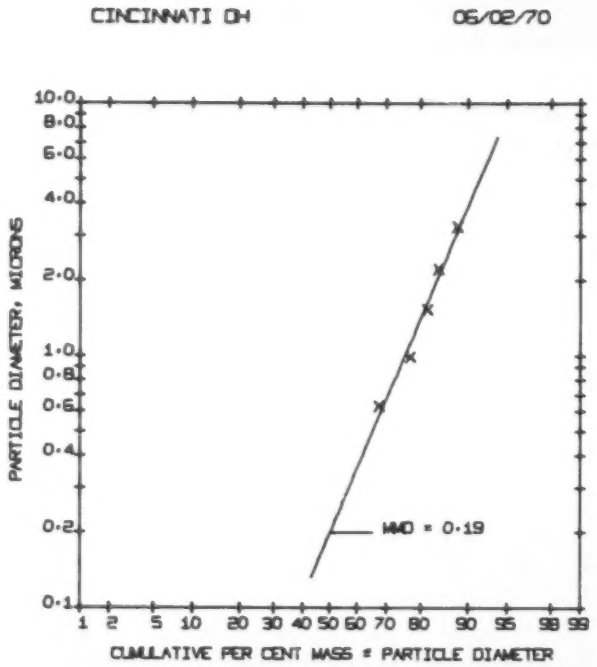

Figure C-6. Particle size distribution curve, Cincinnati, June 2, 1970.

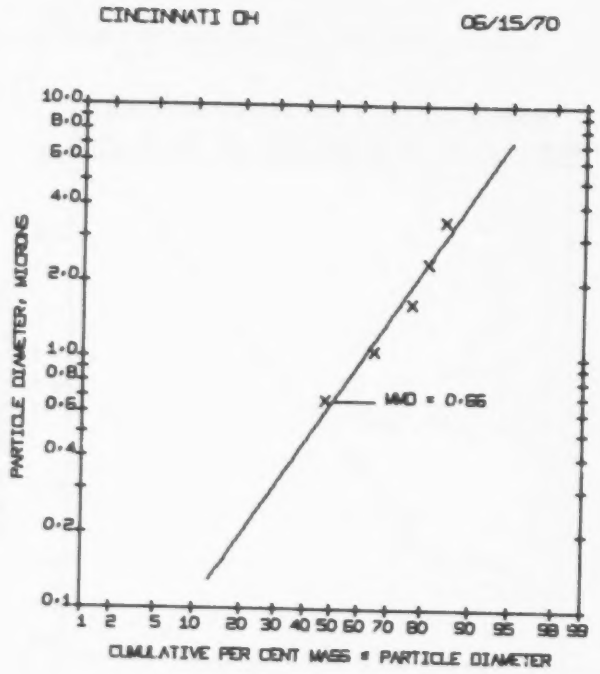

Figure C-7. Particle size distribution curve, Cincinnati, June 15, 1970.

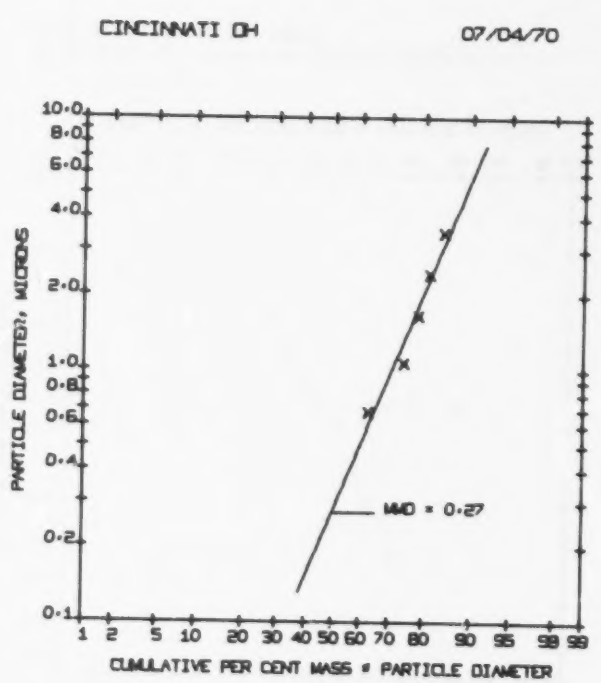

Figure C-8. Particle size distribution curve, Cincinnati, July 4, 1970.

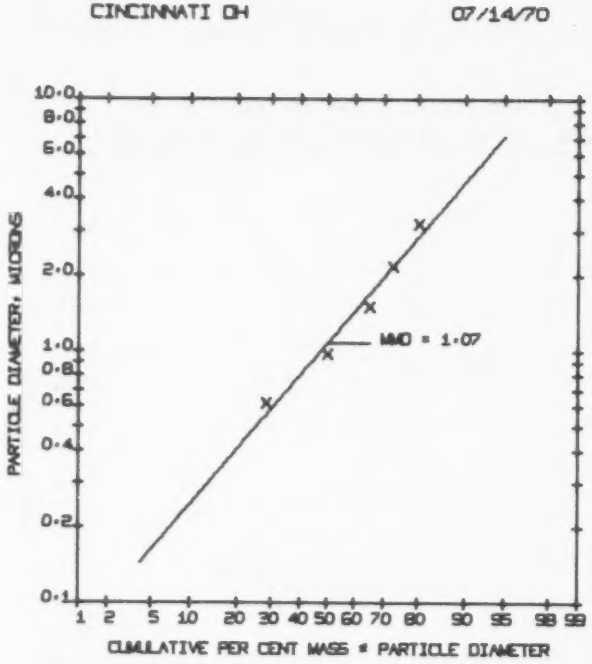

Figure C-9. Particle size distribution curve, Cincinnati, July 14, 1970.

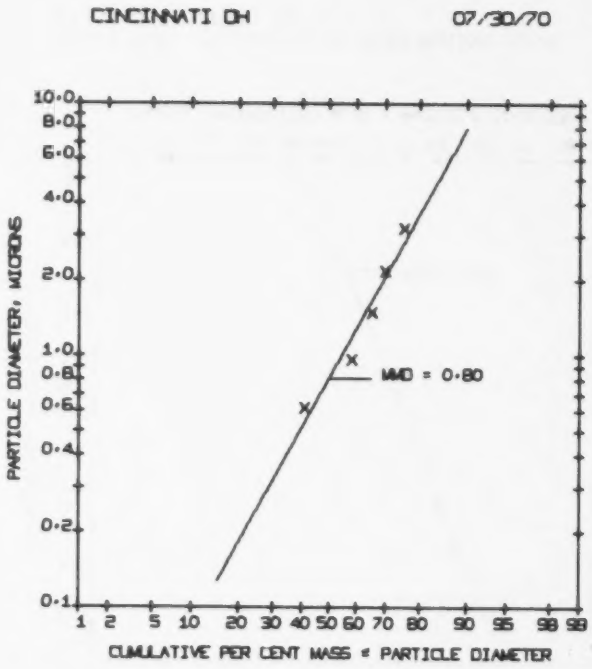

Figure C-10. Particle size distribution curve, Cincinnati, July 30, 1970.

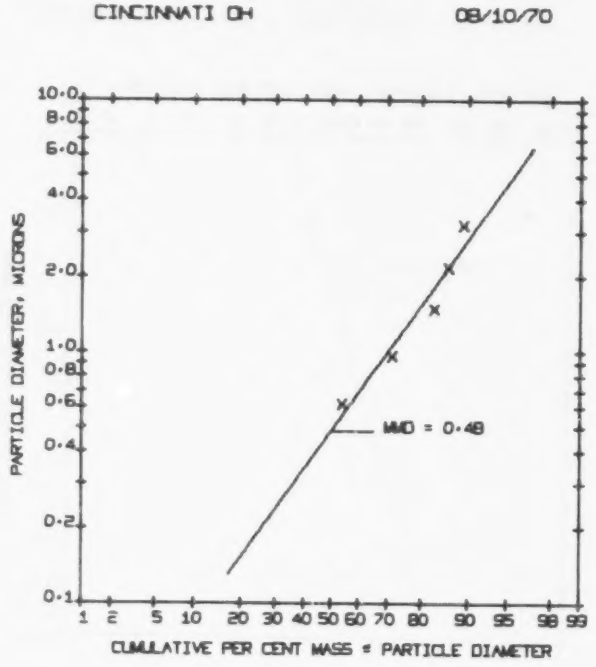

Figure C-11. Particle size distrioution curve, Cincinnati, August 10, 1970.

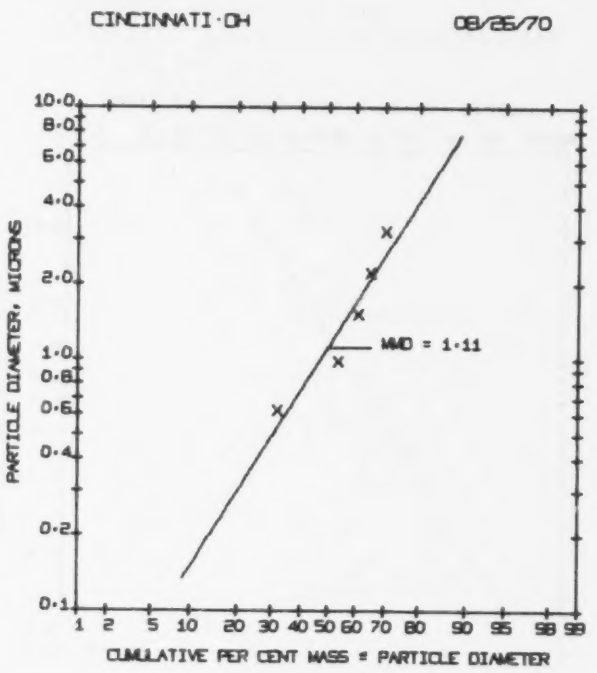

Figure C-12. Particle size distribution curve, Cincinnati, August 26, 1970.

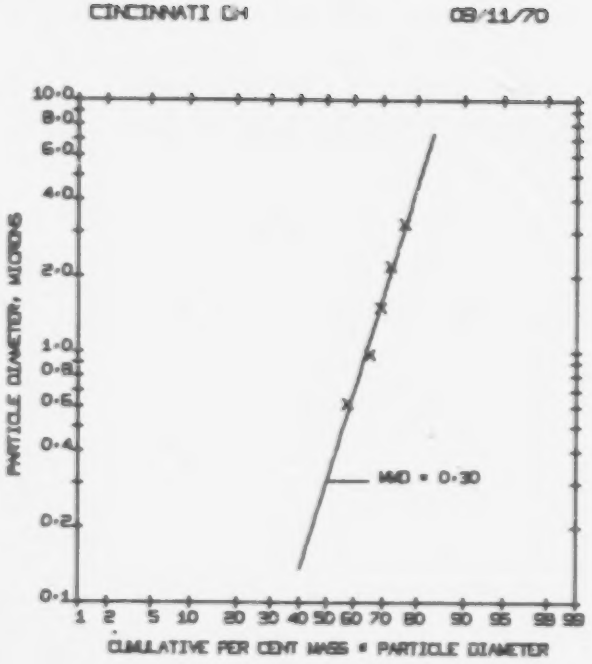

Figure C-13. Particle size distribution curve, Cincinnati, September 11, 1970.

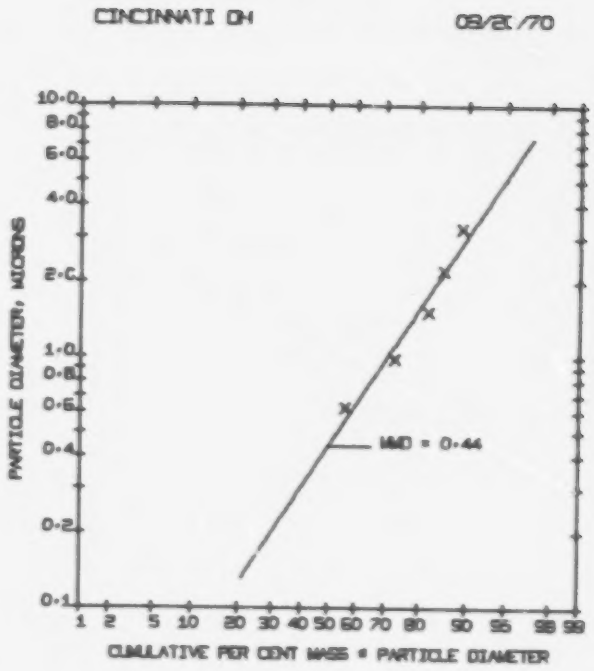

Figure C-14. Particle size distribution curve, Cincinnati, September 20, 1970.

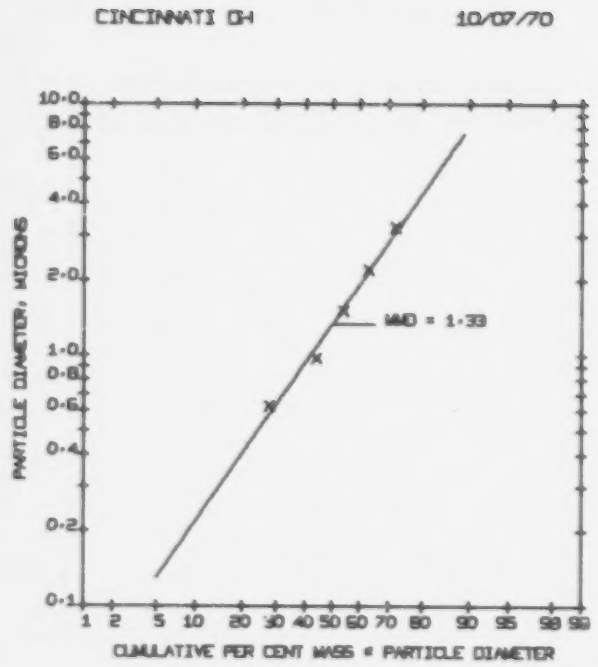

Figure C-15. Particle size distribution curve, Cincinnati, October 7, 1970.

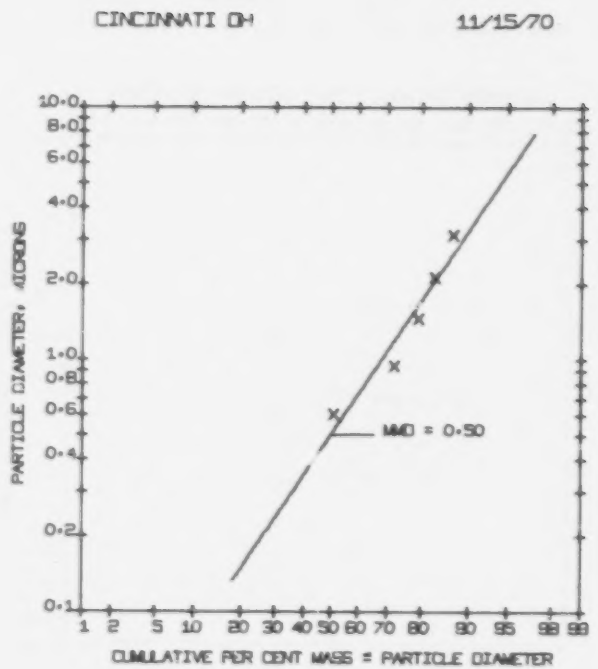

Figure C-16. Particle size distribution curve, Cincinnati, November 15, 1970.

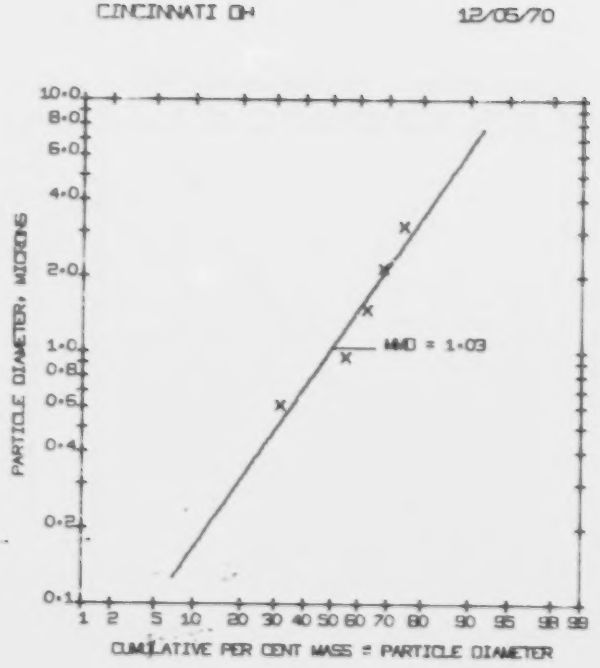

Figure C-17. Particle size distribution curve, Cincinnati, December 5, 1970.

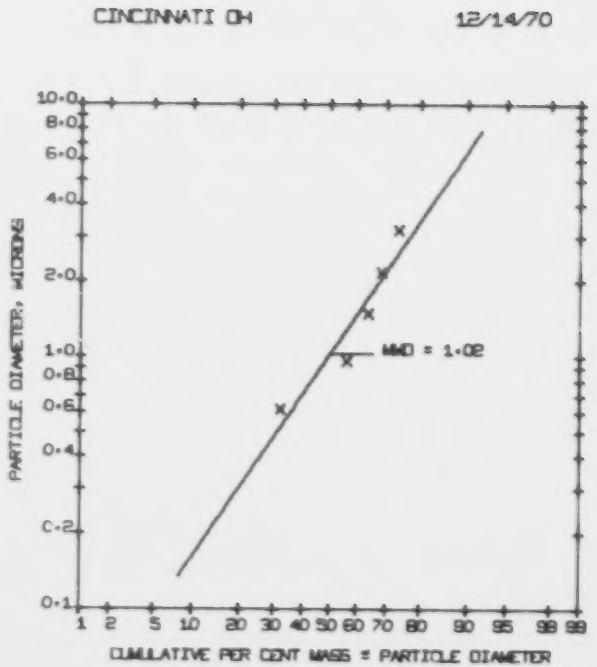

Figure C-18. Particle size distribution curve, Cincinnati, December 14, 1970.

APPENDIX D
DAILY PARTICLE SIZE DISTRIBUTION CURVES, DENVER, COLORADO

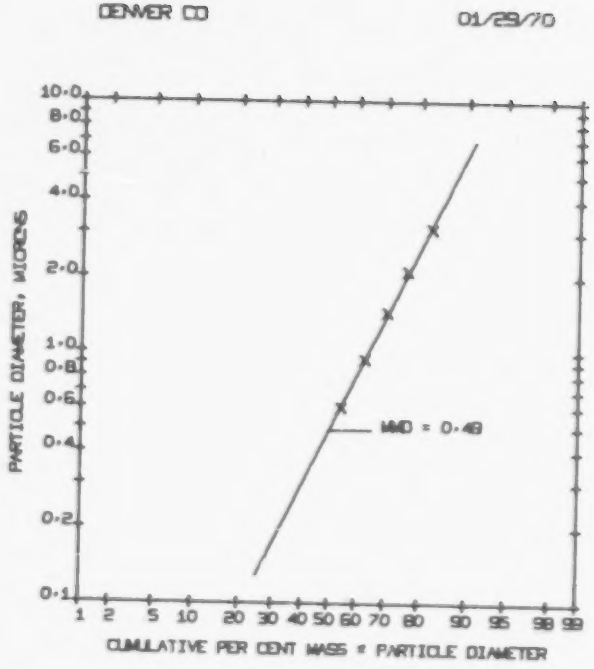

Figure D-1. Particle size distribution curve, Denver, January 29, 1970.

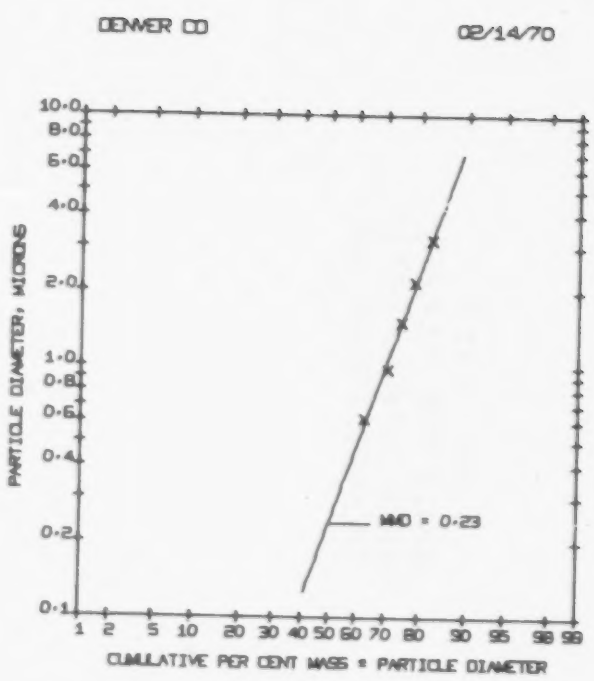

Figure D-2. Particle size distribution curve, Denver, February 14, 1970.

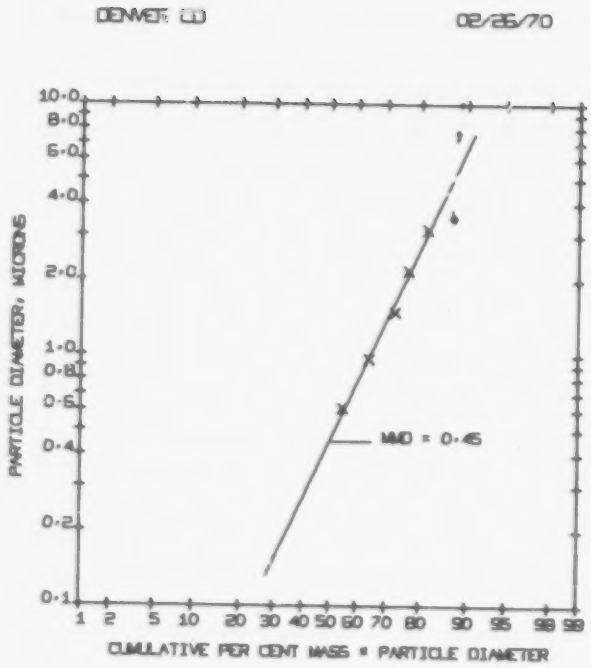

Figure D-3. Particle size distribution curve, Denver, February 26, 1970.

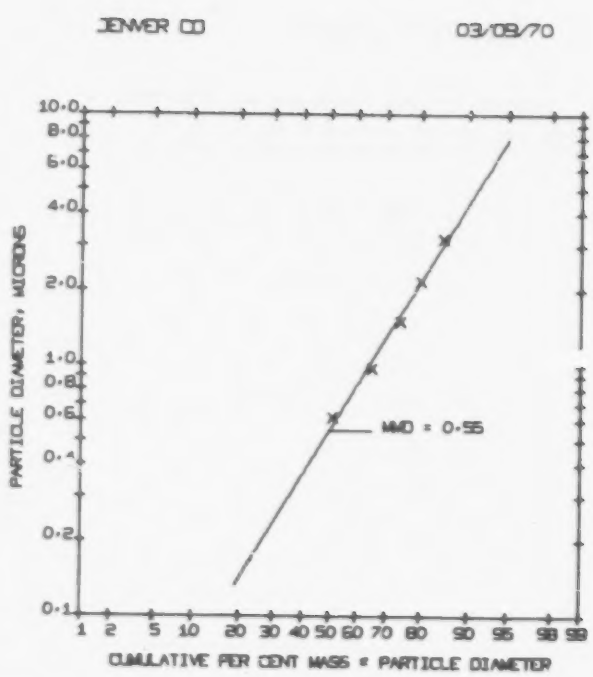

Figure D-4. Particle size distribution curve, Denver, March 9, 1970.

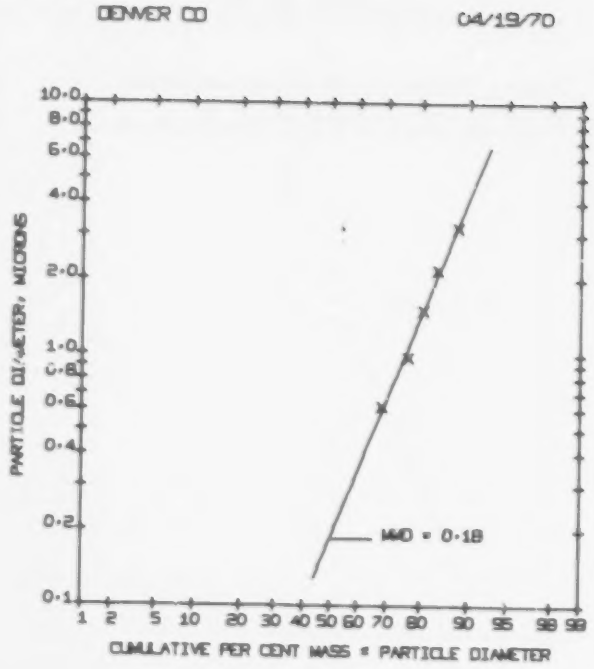

Figure D-5. Particle size distribution curve, Denver, April 19, 1970.

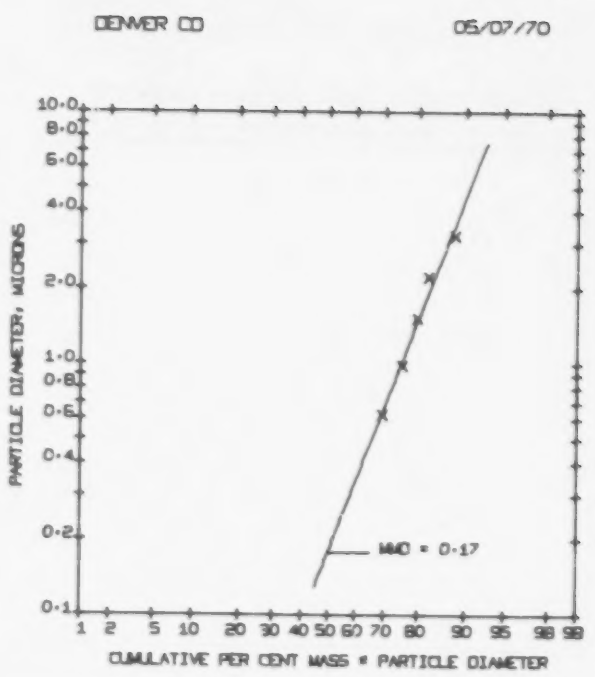

Figure D-6. Particle size distribution curve, Denver, May 7, 1970.

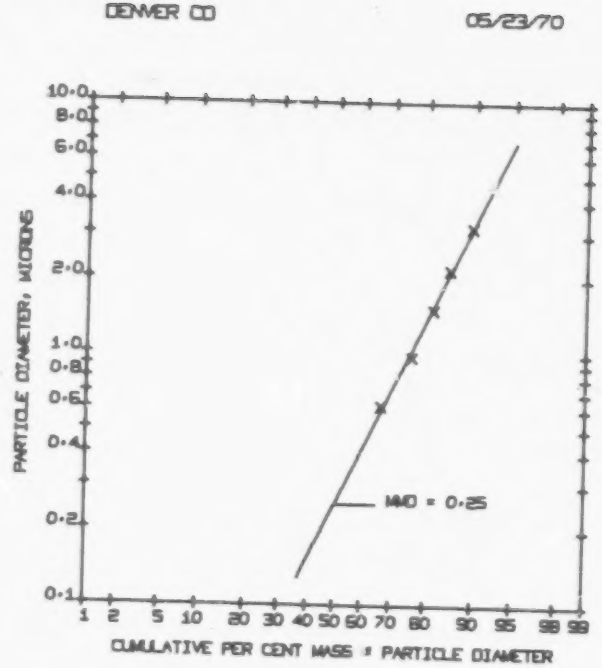

Figure D-7. Particle size distribution curve, Denver, May 23, 1970.

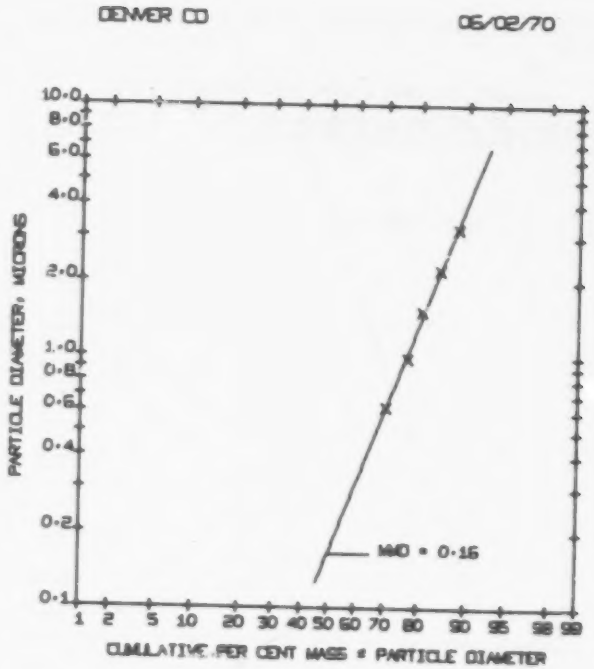

Figure D-8. Particle size distribution curve, Denver, June 2, 1970.

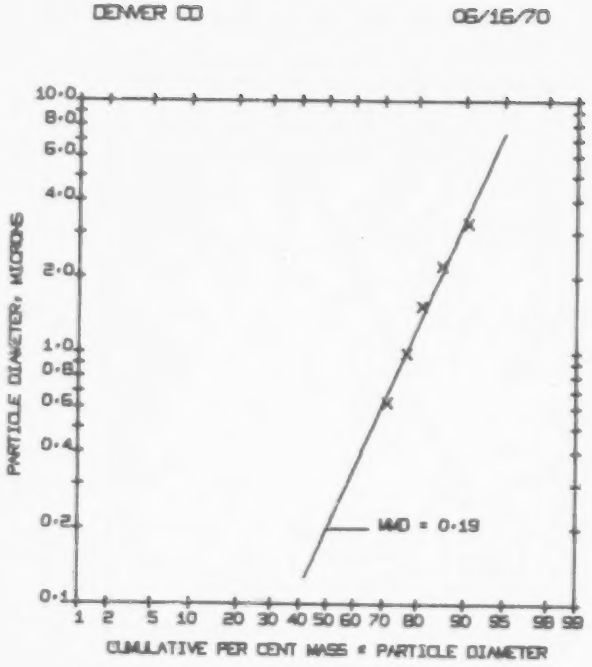

Figure D-9 Particle size distribution curve, Denver, June 16, 1970.

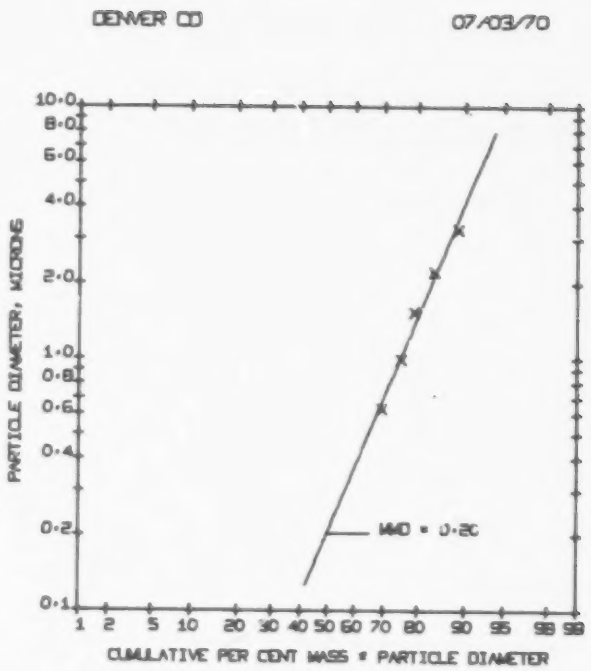

Figure D-10. Particle size distribution curve, Denver, July 3, 1970.

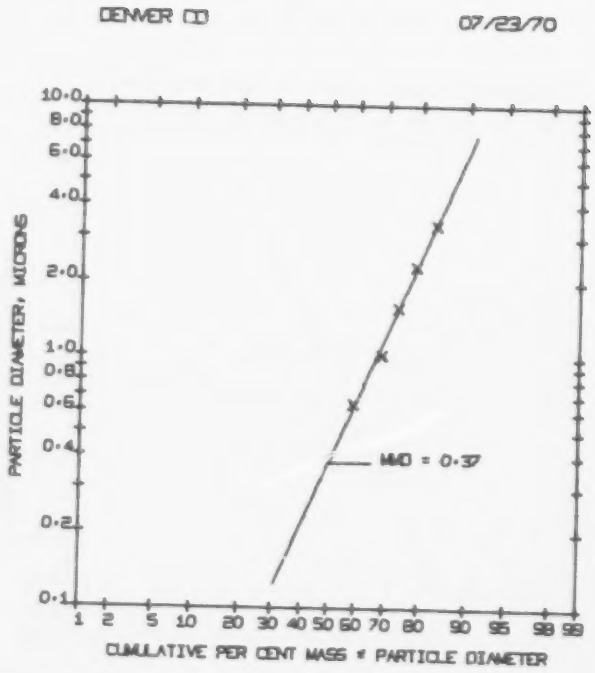

Figure D-11. Particle size distribution curve, Denver, July 23, 1970.

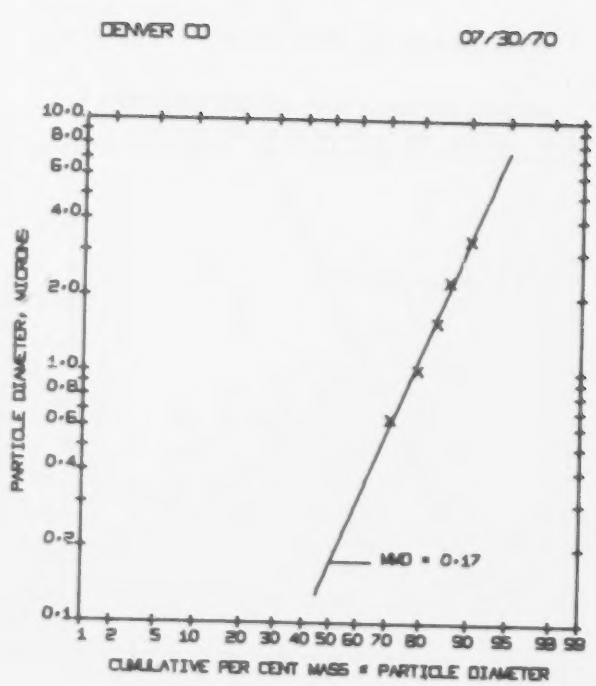

Figure D-12. Particle size distribution curve, Denver, July 30, 1970.

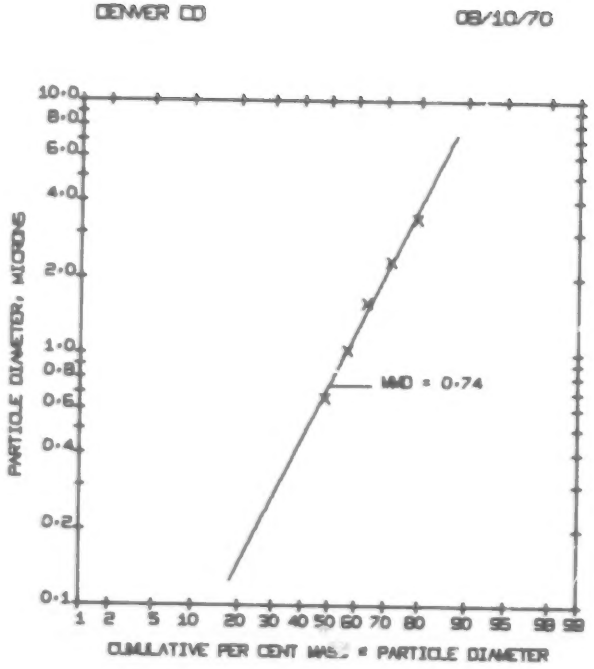

Figure D-13. Particle size distribution curve, Denver, August 10, 1970.

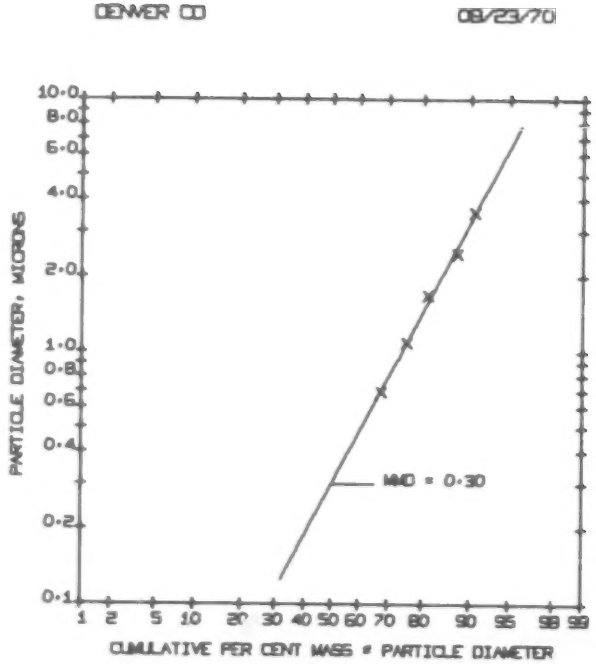

Figure D-14. Particle size distribution curve, Denver, August 23, 1970.

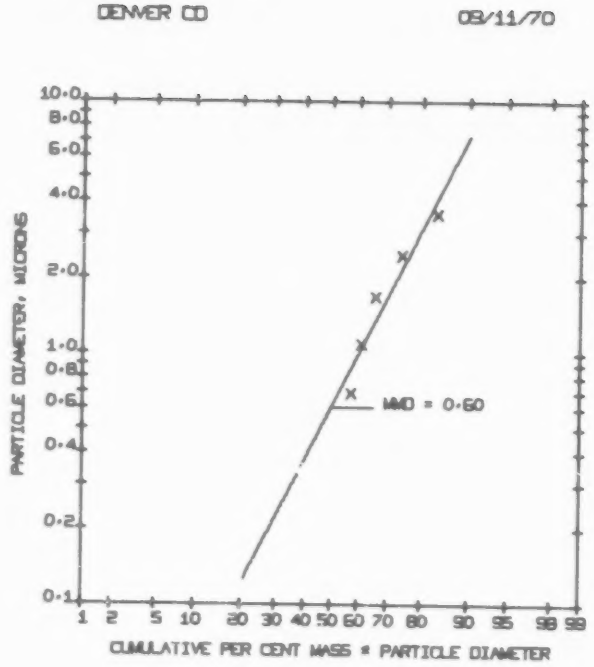

Figure D-15. Particle size distribution curve, Denver, September 11, 1970.

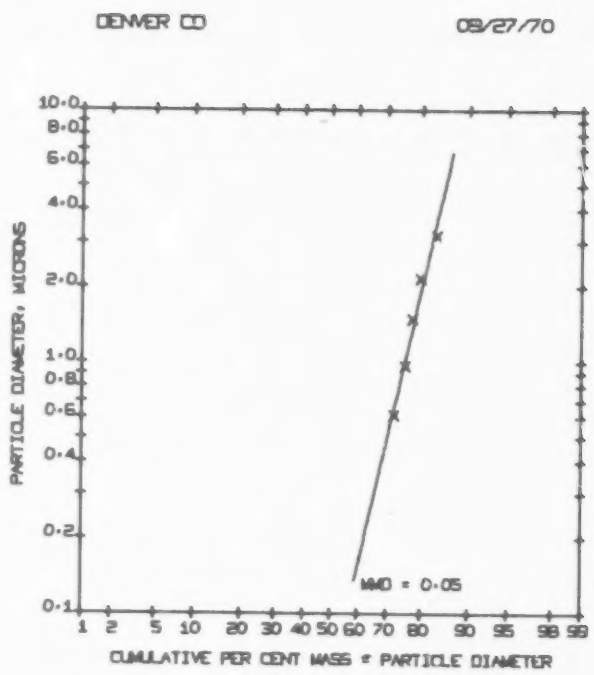

Figure D-16. Particle size distribution curve, Denver, September 27, 1970.

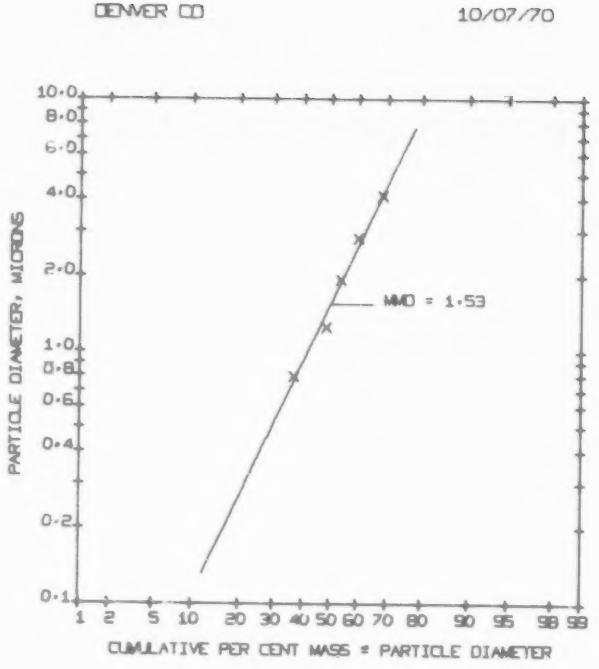

Figure D-17. Particle size distribution curve, Denver, October 7, 1970.

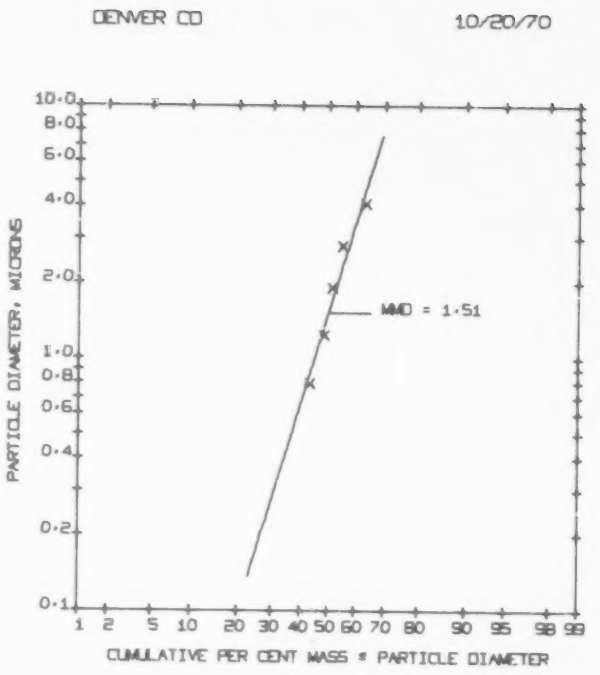

Figure D-18. Particle size distribution curve, Denver, October 20, 1970.

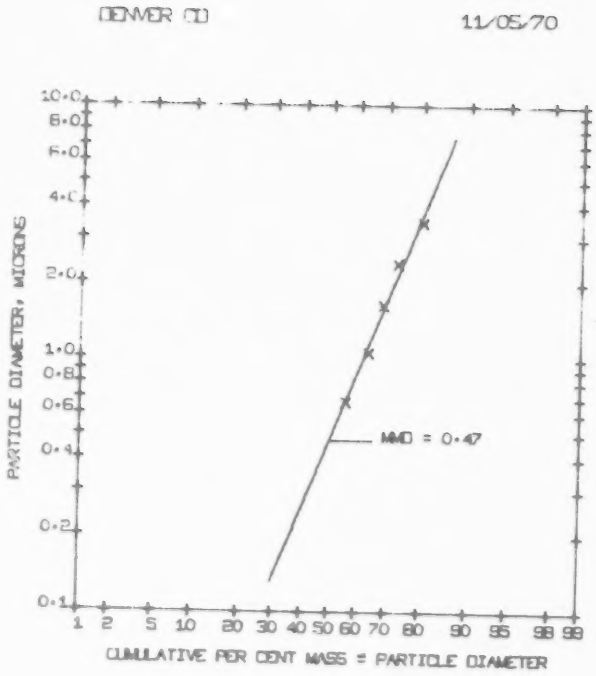

Figure D-19. Particle size distribution curve, Denver, November 5, 1970.

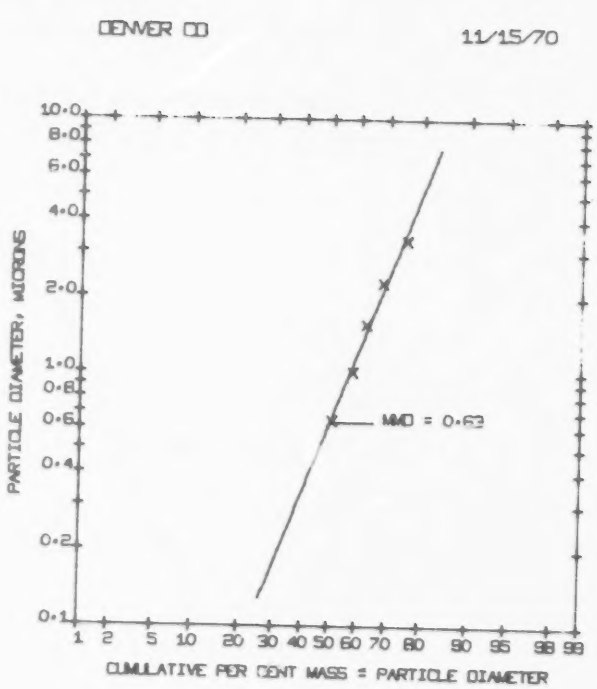

Figure D-20. Particle size distribution curve, Denver, November 15, 1970.

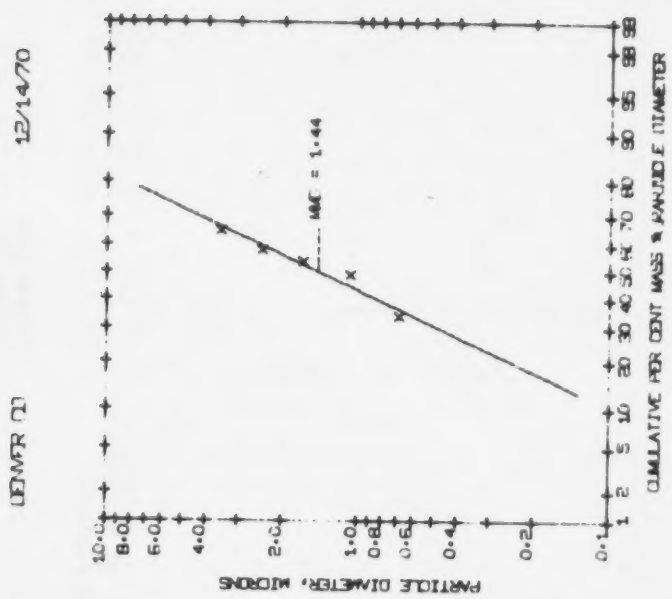

Figure D-21. Particle size distribution curve, Denver, December 14, 1970.

APPENDIX E
DAILY PARTICLE SIZE DISTRIBUTION CURVES, PHILADELPHIA, PENNSYLVANIA

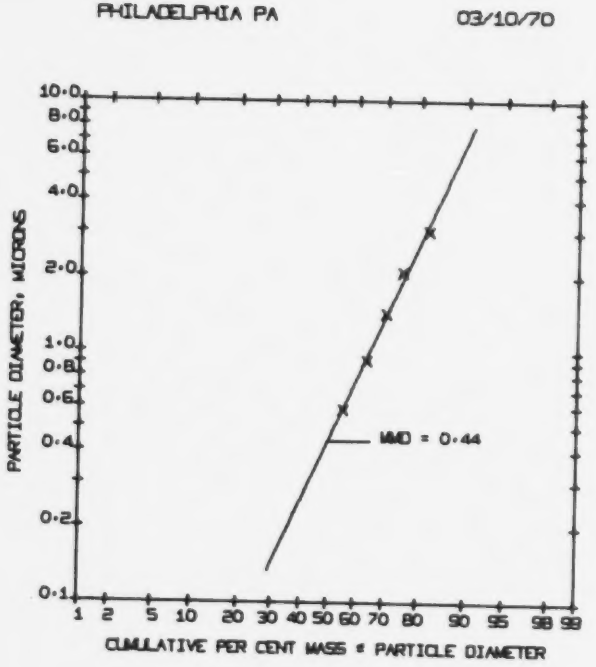

Figure E-1. Particle size distribution curve, Philadelphia, March 10, 1970.

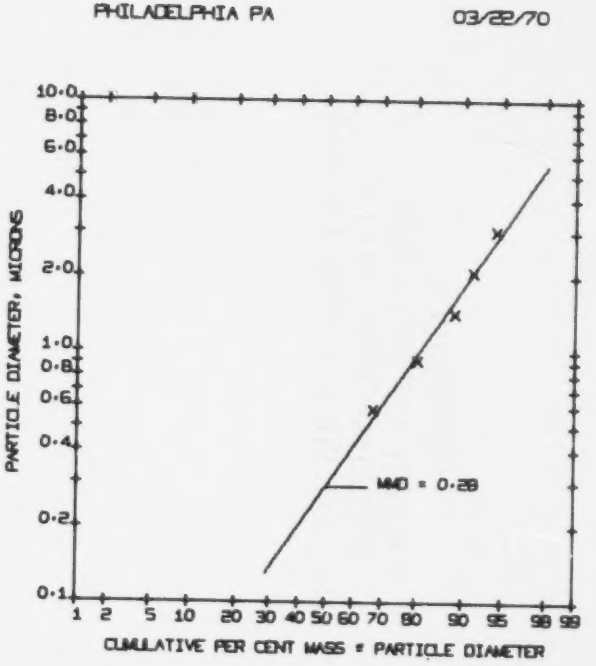

Figure E-2. Particle size distribution curve, Philadelphia, March 22, 1970.

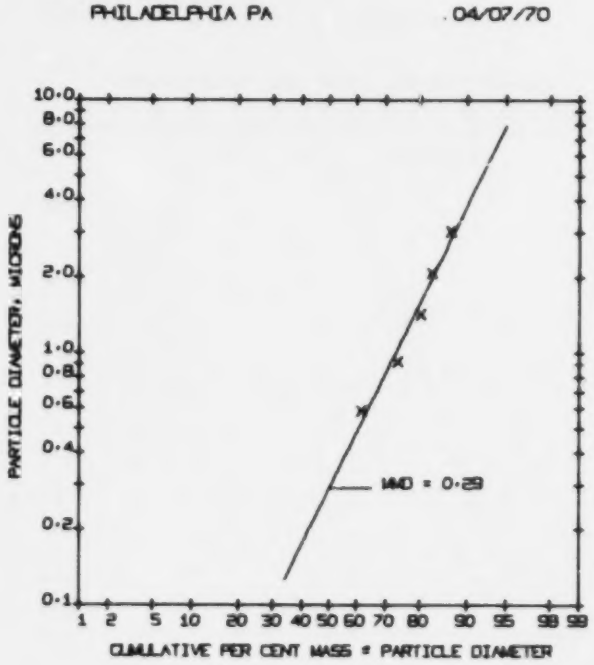

Figure E-3. Particle size distribution curve, Philadelphia, April 7, 1970.

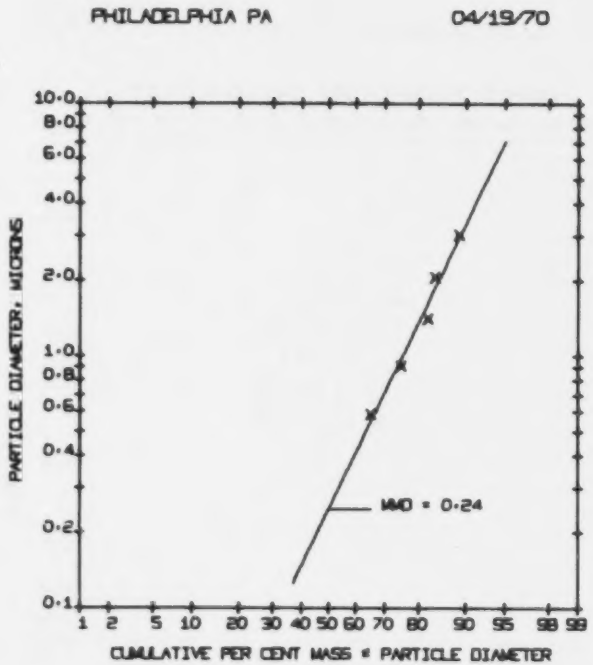

Figure E-4. Particle size distribution curve, Phildelphia, April 19, 1970.

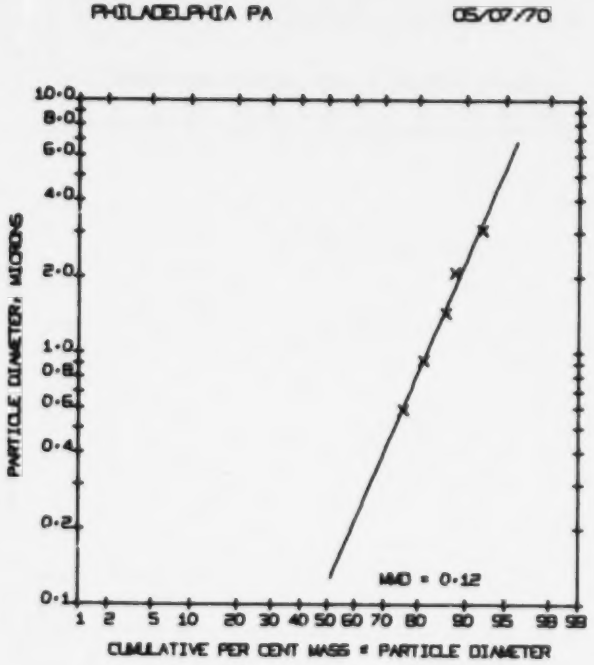

Figure E-5. Particle size distribution curve, Philadelphia, May 7, 1970.

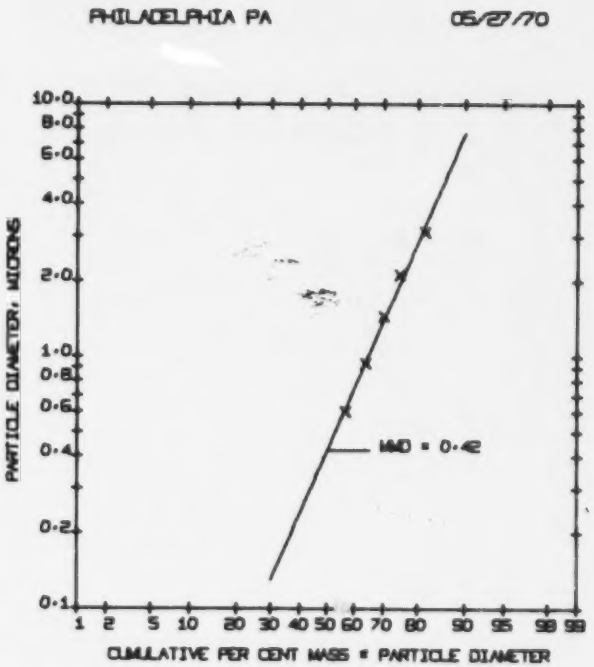

Figure E-6. Particles size distribution curve, Philadelphia, May 27, 1970.

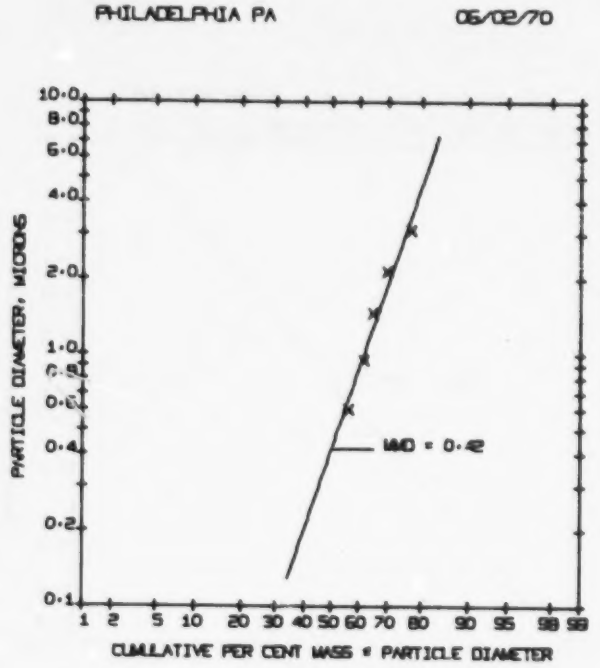

Figure E-7. Particle size distribution curve, Philadelphia, June 2, 1970.

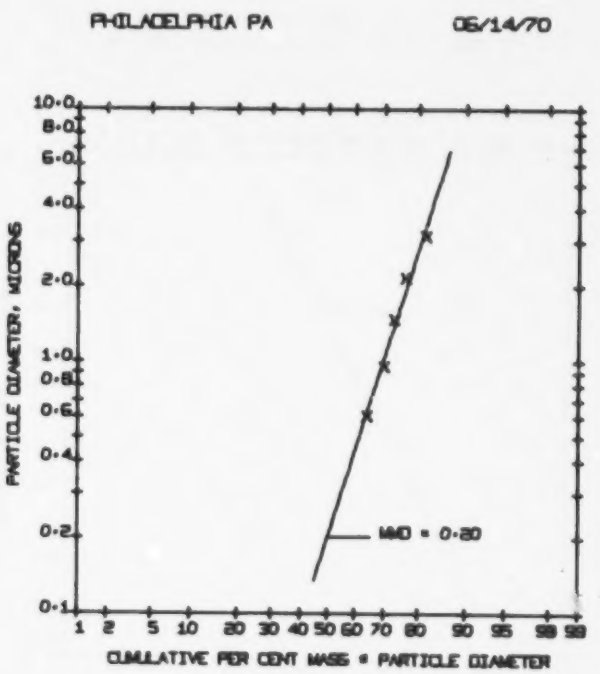

Figure E-8. Particle size distribution curve, Philadelphia, June 14, 1970.

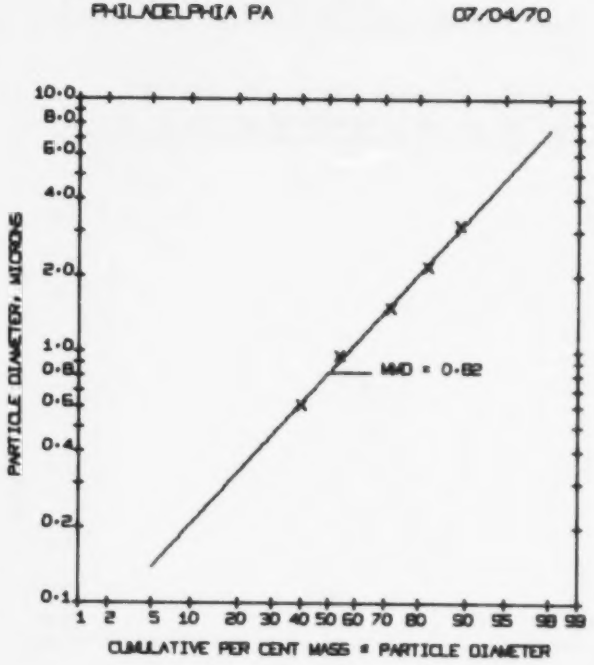

Figure E-9. Particle size distribution curve, Philadelphia, July 4, 1970.

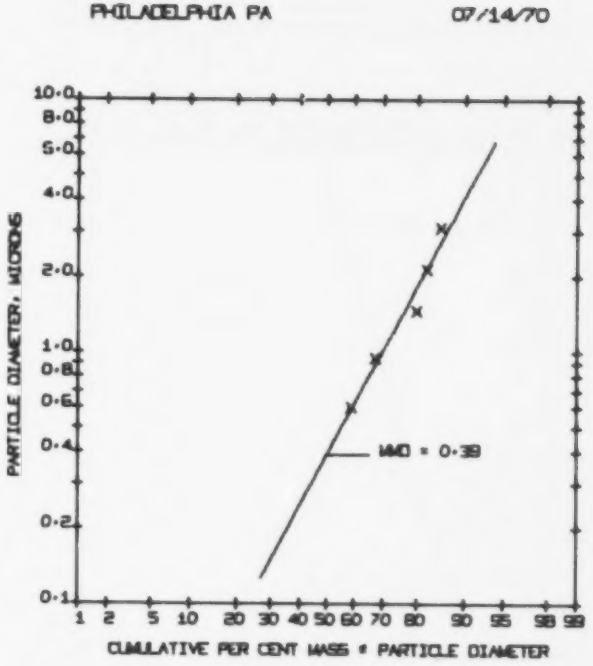

Figure E-10. Particle size distribution curve, Philadelphia, July 14, 1970.

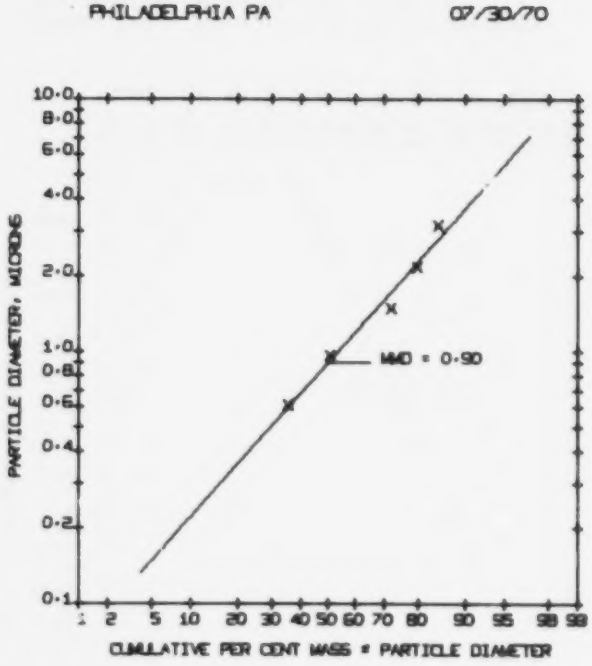

Figure E-11. Particle size distribution curve, Philadelphia, July 30, 1970.

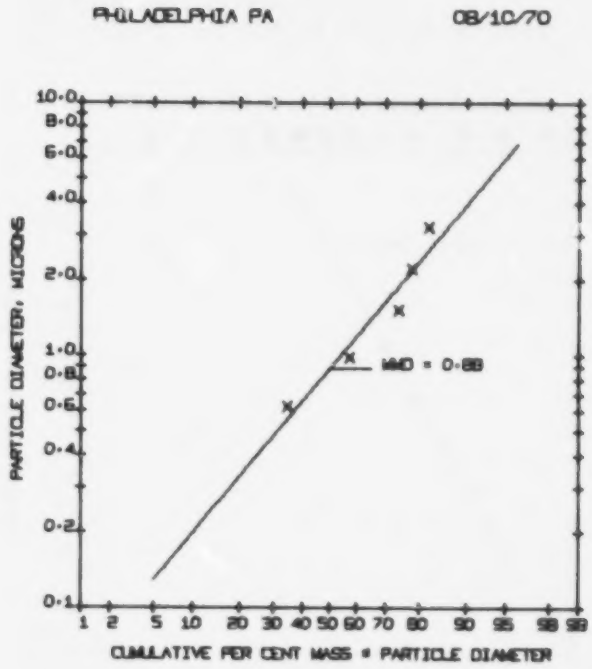

Figure E-12. Particle size distribution curve, Philadelphia, August 10, 1970.

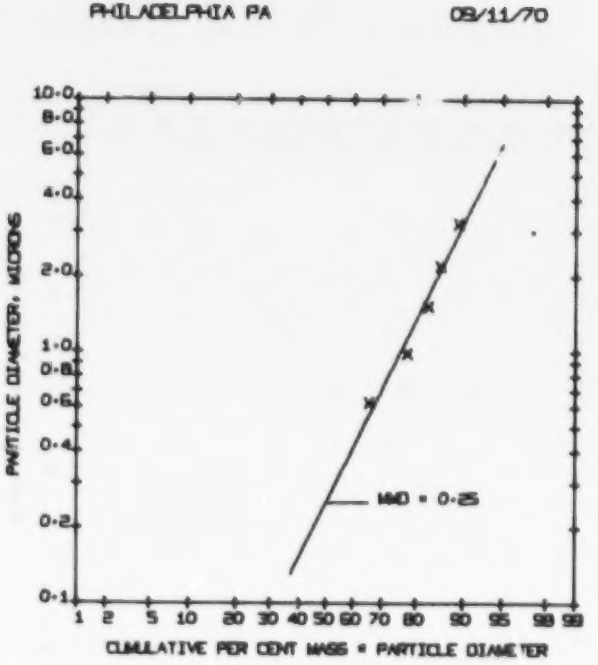

Figure E-13. Particle size distribution curve, Philadelphia, September 11, 1970.

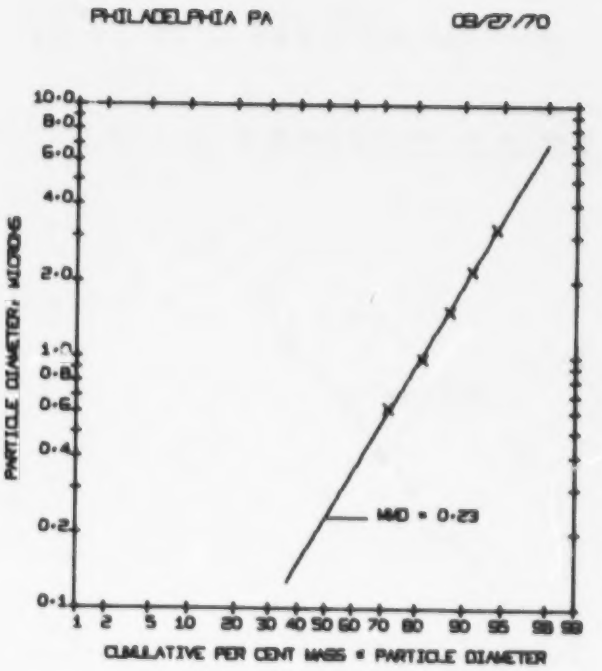

Figure E-14. Particle size distribution curve, Philadelphia, September 27, 1970.

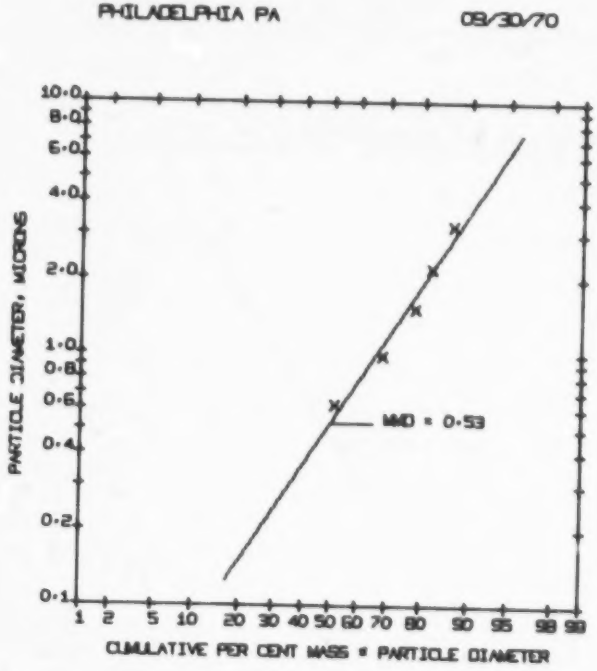

Figure E-15. Particle size distribution curve, Philadelphia, September 30, 1970.

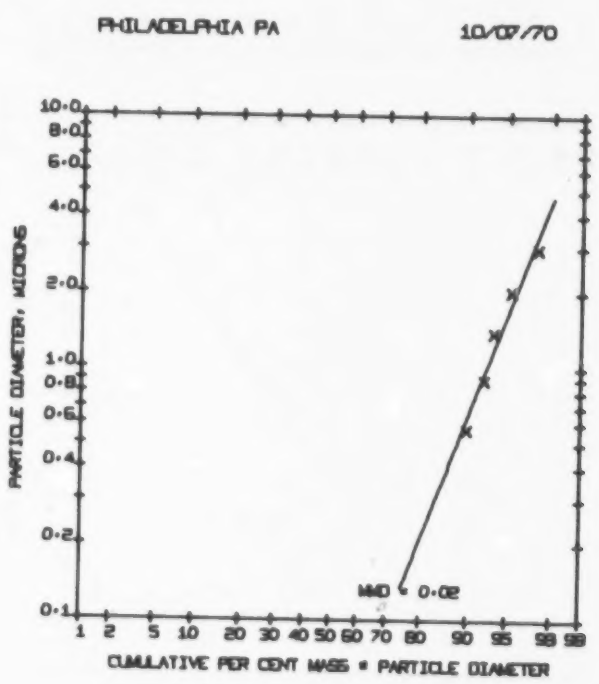

Figure E-16. Particle size distribution curve, Philadelphia, October 7, 1970.

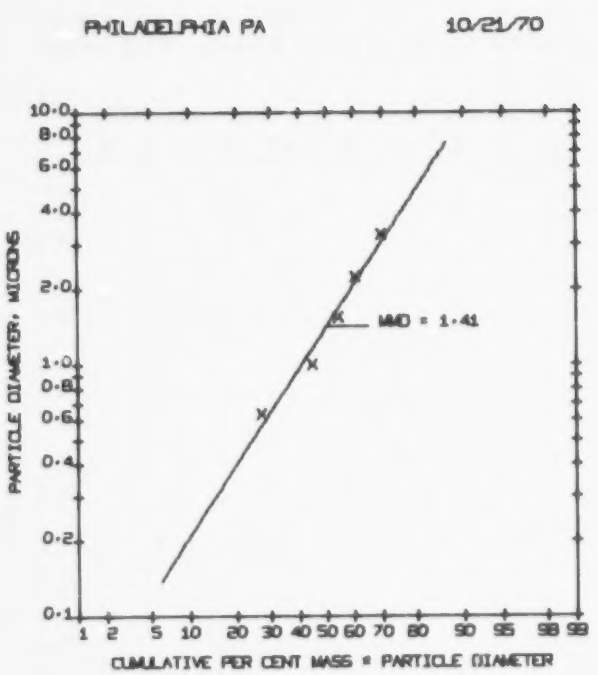

Figure E-17. Particle size distribution curve, Philadelphia, October 21, 1970.

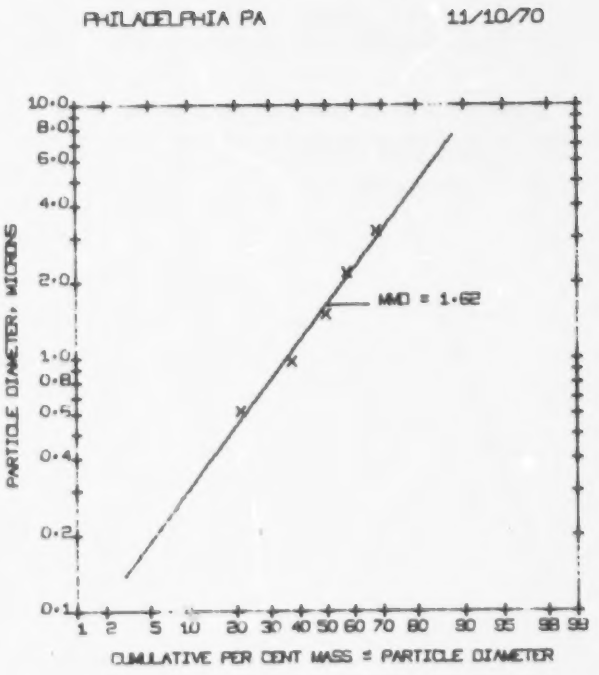

Figure E-18. Particle size distribution curve, Philadelphia, November 10, 1970.

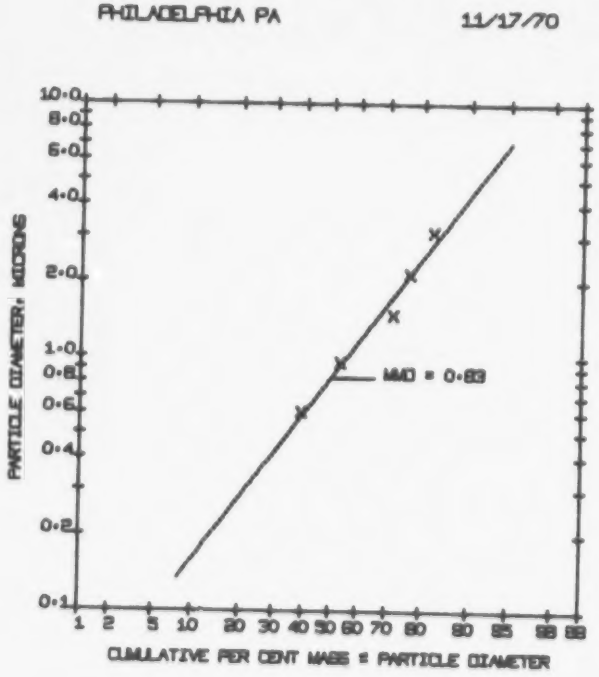

Figure E-19. Particle size distribution curve, Philadelphia, November 17, 1970.

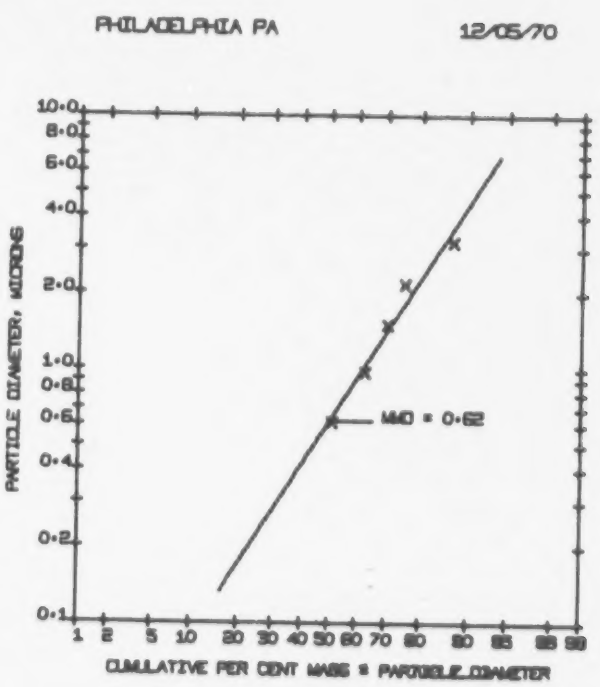

Figure E-20. Particle size distribution curve, Philadelphia, December 5, 1970.

APPENDIX F
DAILY PARTICLE SIZE DISTRIBUTION CURVES, ST. LOUIS, MISSOURI

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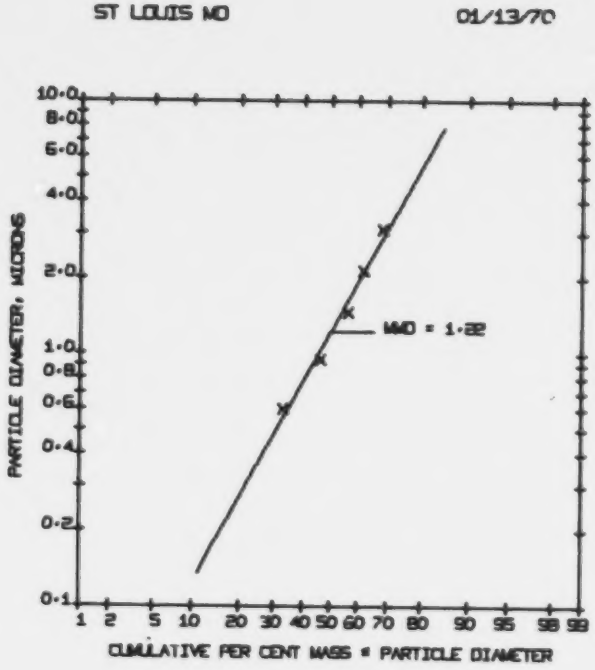

Figure F-1. Particle size distribution curve, St. Louis, January 13, 1970.

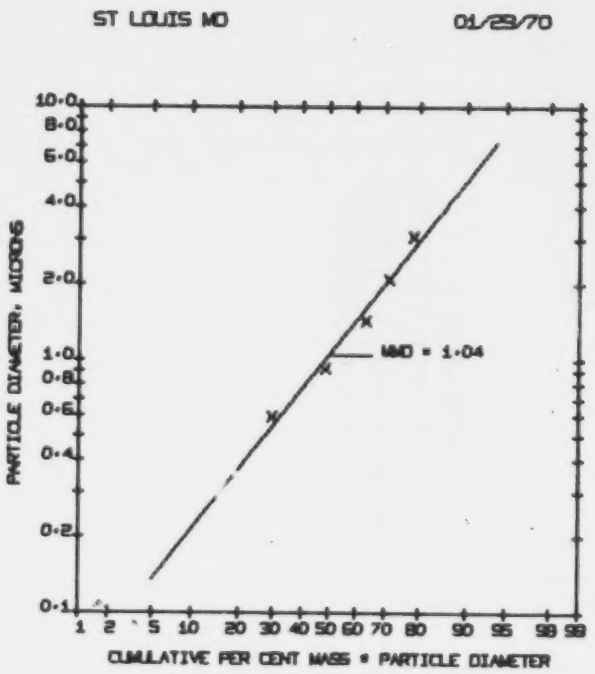

Figure F-2. Particle size distribution curve, St. Louis, January 29, 1970.

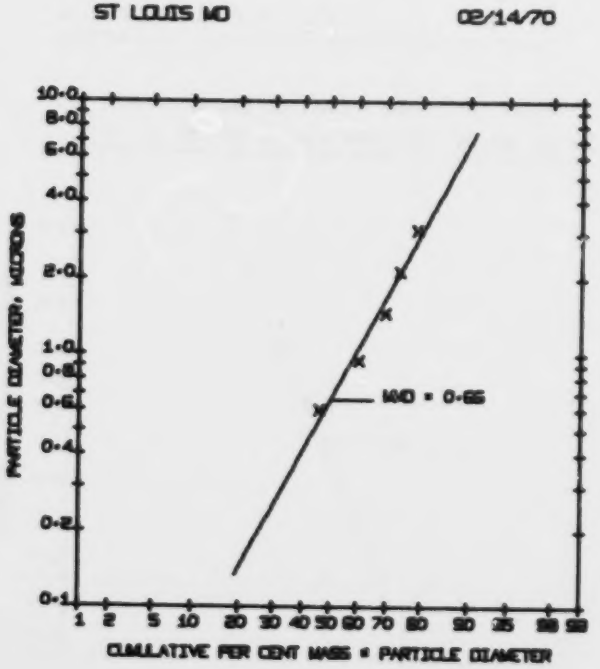

Figure F-3. Particle size distribution curve, St. Louis, February 14, 1970.

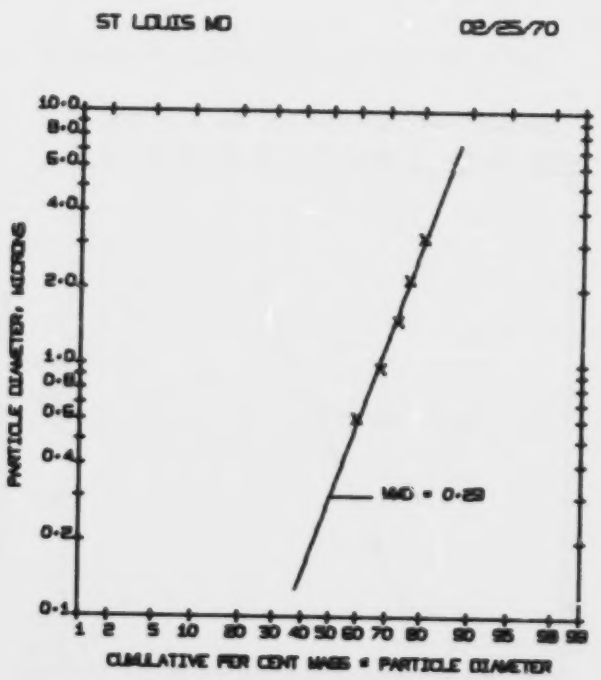

Figure F-4. Particle size distribution curve, St. Louis, February 25, 1970.

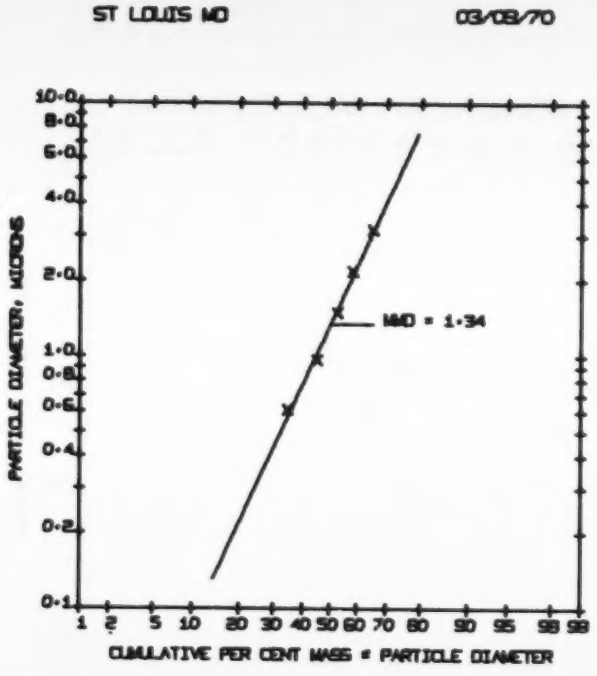

Figure F-5. Particle size distribution curve, St. Louis, March 9, 1970.

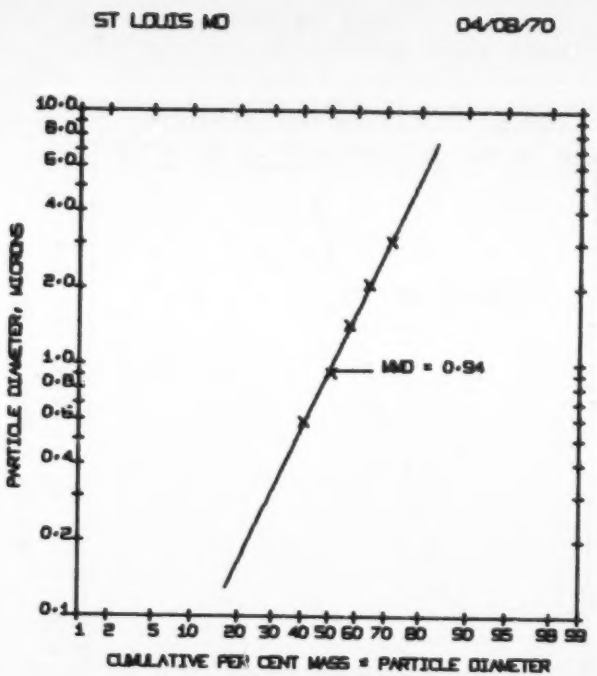

Figure F-6. Particle size distribution curve, St. Louis, April 8, 1970.

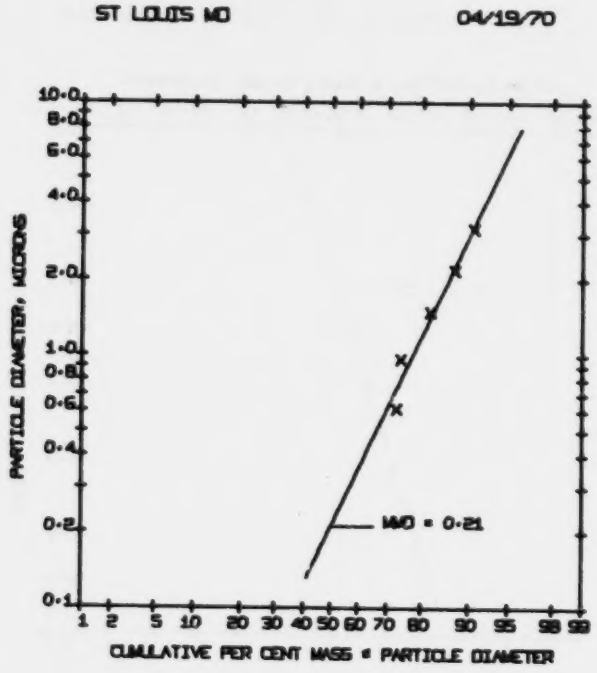

Figure F-7. Particle size distribution curve, St. Louis, April 19, 1970.

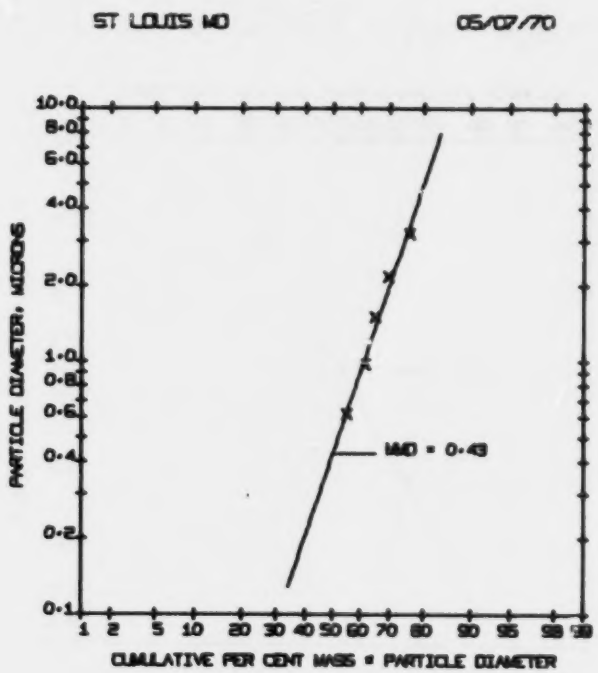

Figure F-8. Particle size distribution curve, St. Louis, May 7, 1970.

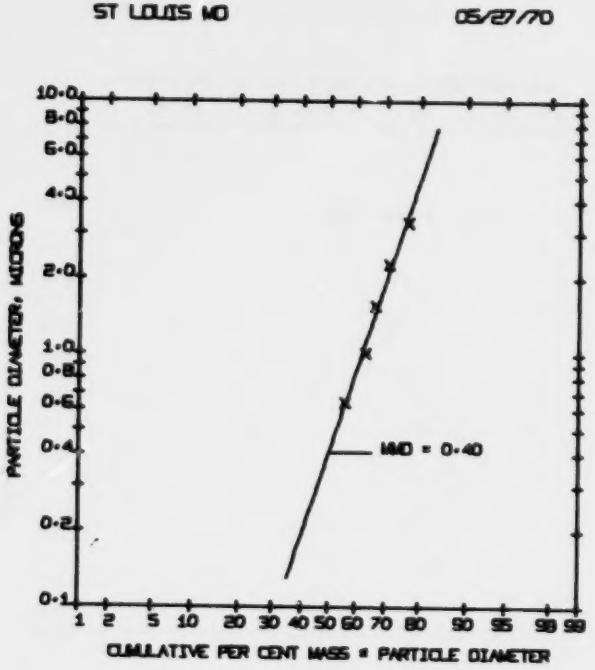

Figure F-9. Particle size distribution curve, St. Louis, May 27, 1970.

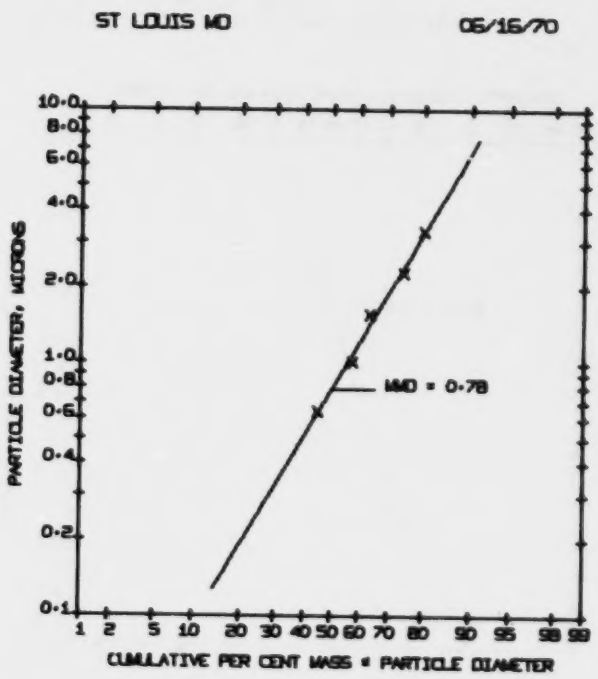

Figure F-10. Particle size distribution curve, St. Louis, June 16, 1970.

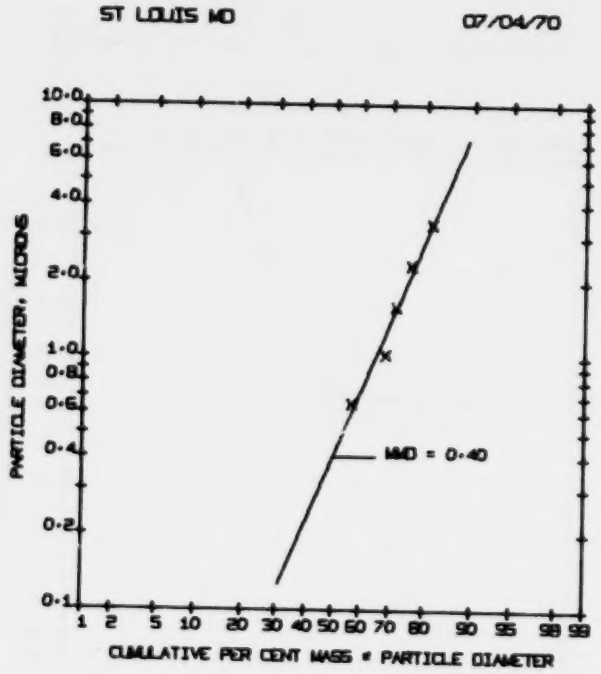

Figure F-11. Particle size distribution curve, St. Louis, July 4, 1970.

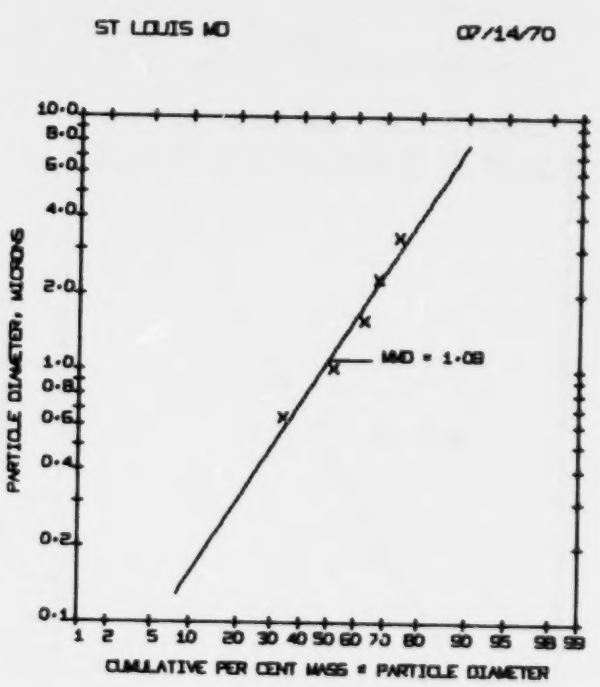

Figure F-12. Particle size distribution curve, St. Louis, July 14, 1970.

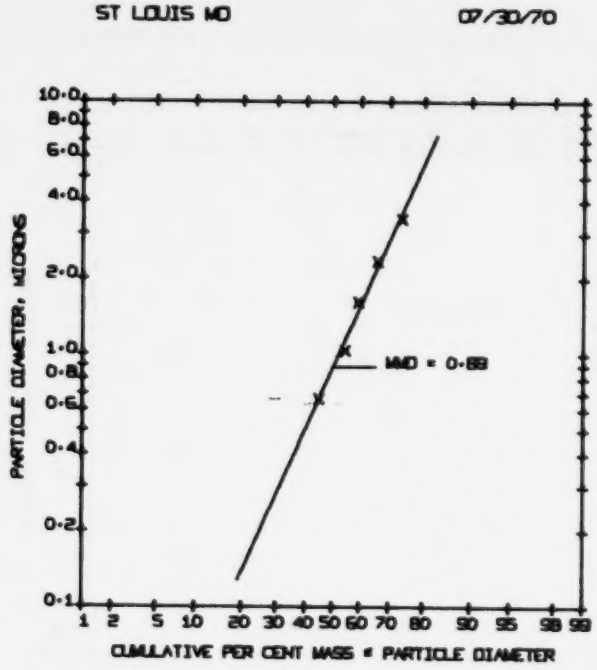

Figure F-13. Particle size distribution curve, St. Louis, July 30, 1970.

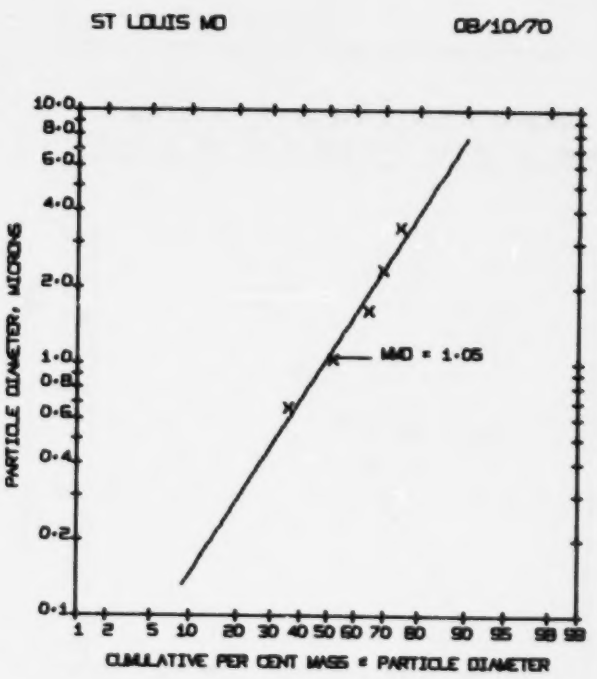

Figure F-14. Particle size distribution curve, St. Louis, August 10, 1970.

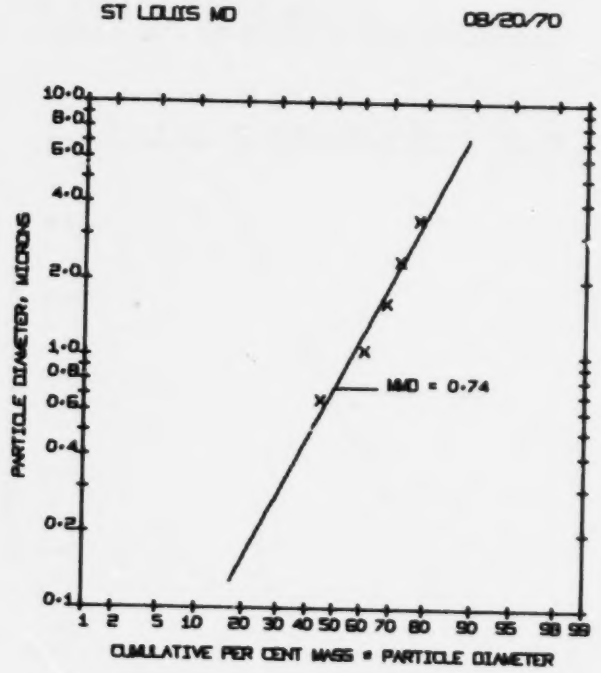

Figure F-15. Particle size distribution curve, St. Louis, August 20, 1970.

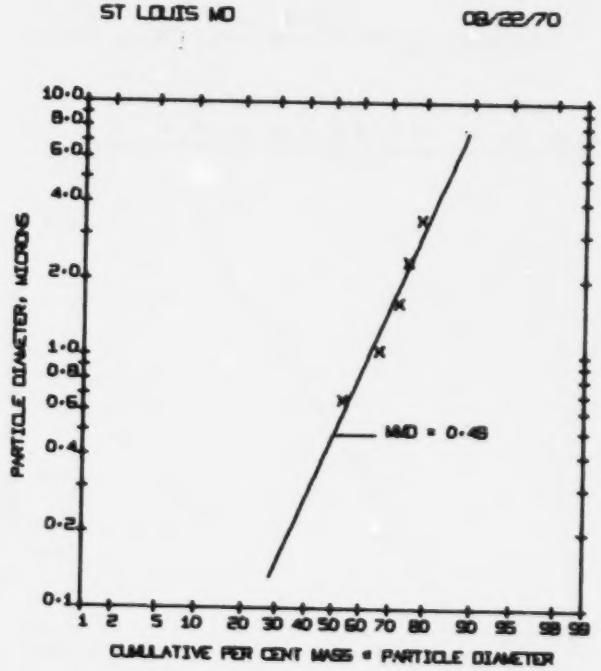

Figure F-16. Particle size distribution curve, St. Louis, August 22, 1970.

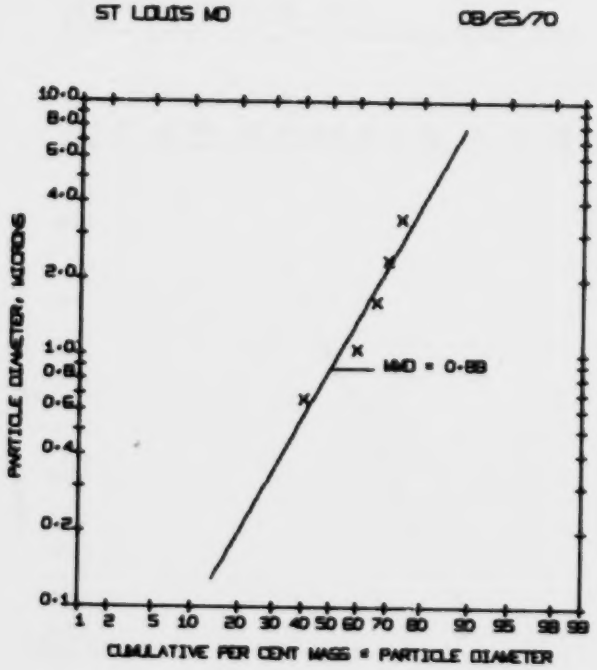

Figure F-17. Particle size distribution curve, St. Louis, August 25, 1970.

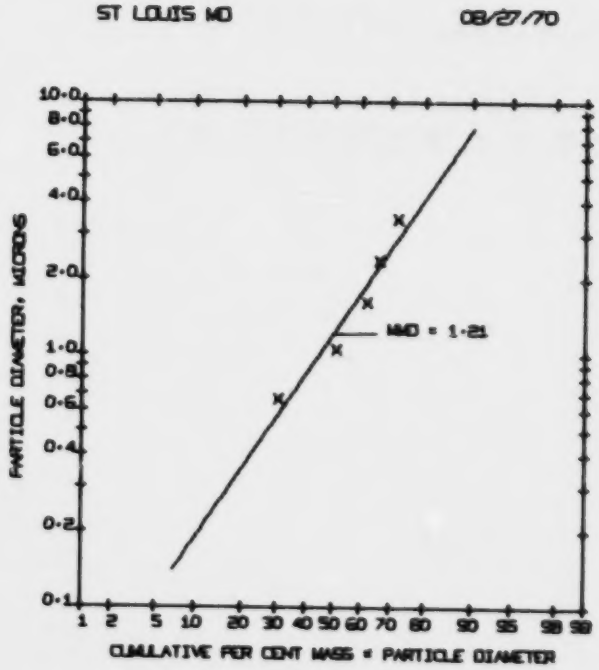

Figure F-18. Particle size distribution curve, St. Louis, August 27, 1970.

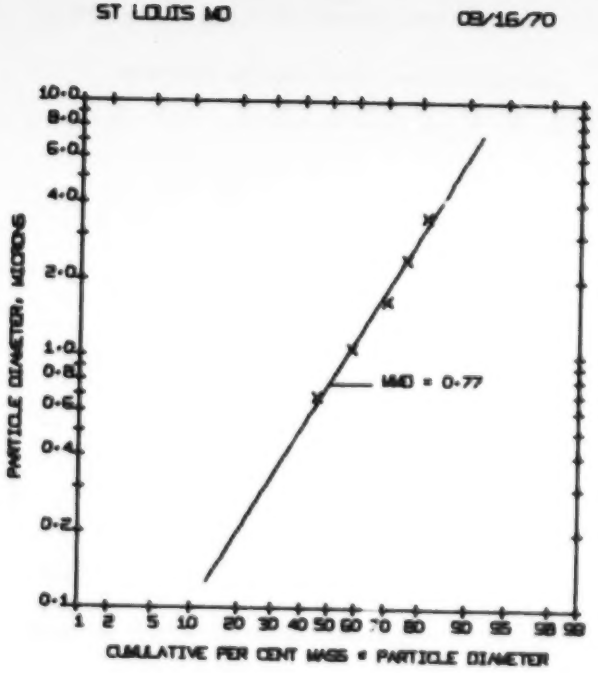

Figure F-19. Particle size distribution curve, St. Louis, September 16, 1970.

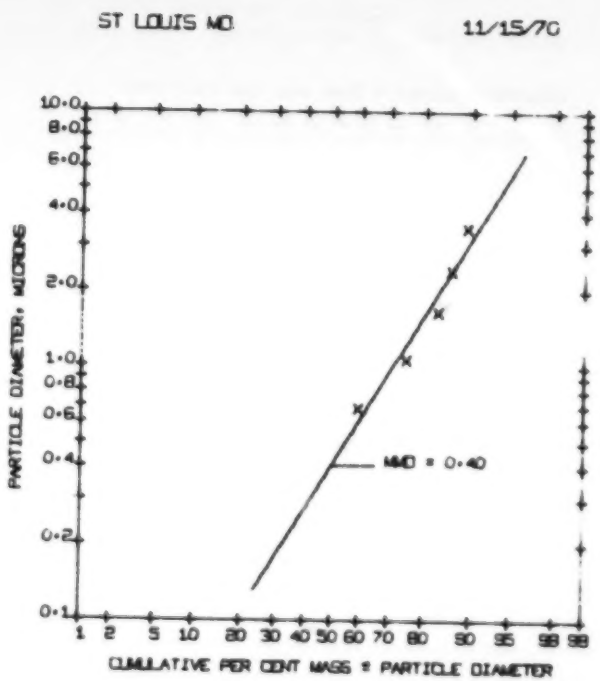

Figure F-20. Particle size distribution curve, St. Louis, November 15, 1970.

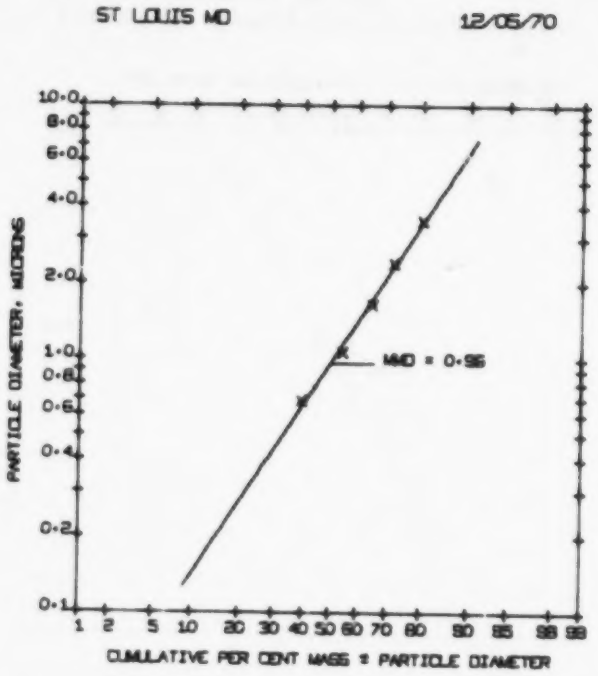

Figure F-21. Particle size distribution curve, St. Louis, December 5, 1970.

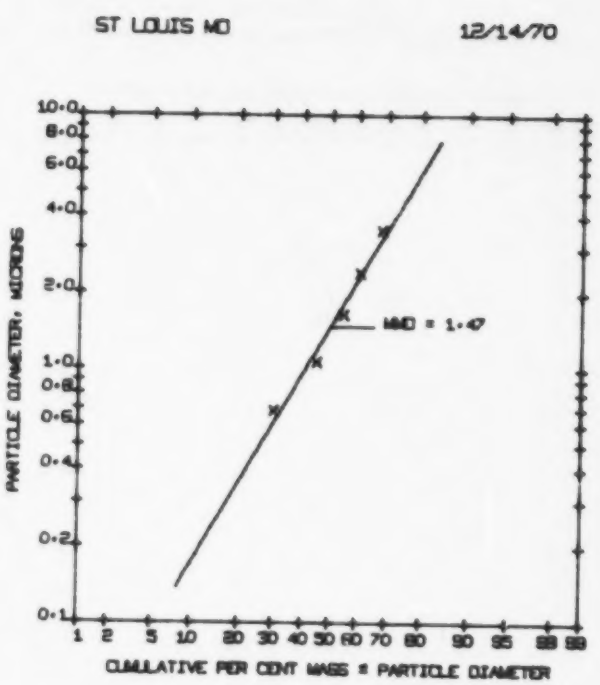

Figure F-22. Particle size distribution curve, St. Louis, December 14, 1970.

APPENDIX G
DAILY PARTICLE SIZE DISTRIBUTION CURVES, WASHINGTON, D. C.

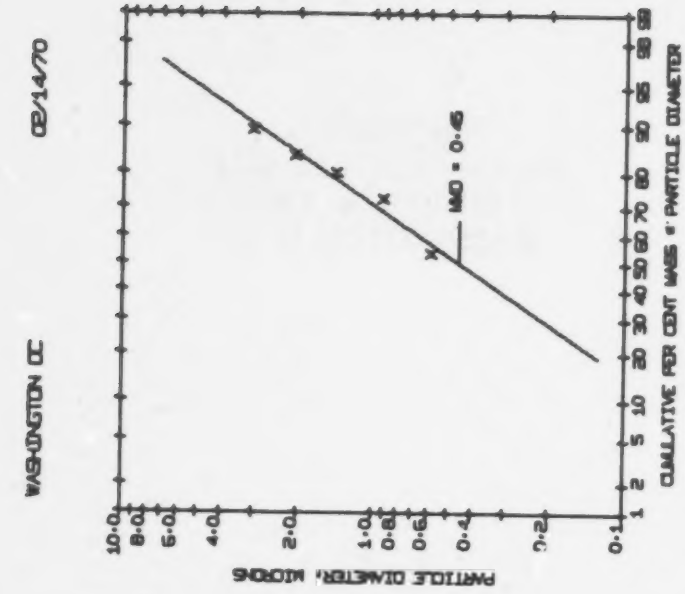

Figure G-2. Particle size distribution curve, Washington, D.C., February 14, 1970.

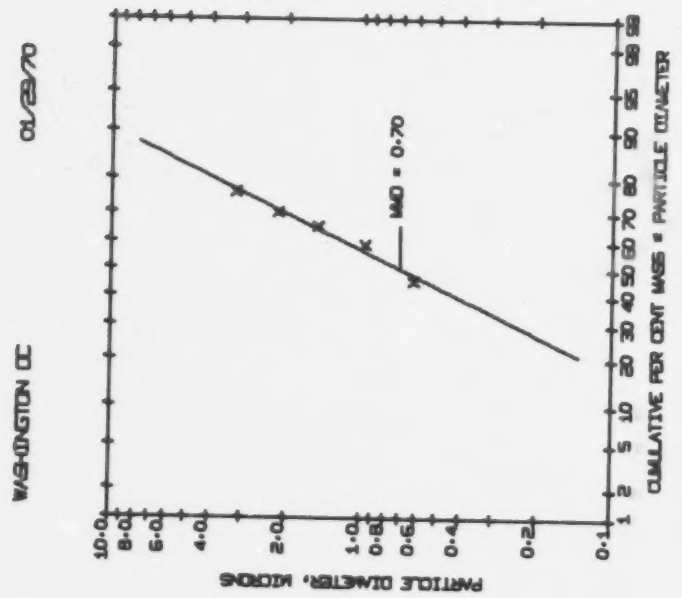

Figure G-1. Particle size distribution curve, Washington, D.C., January 29, 1970.

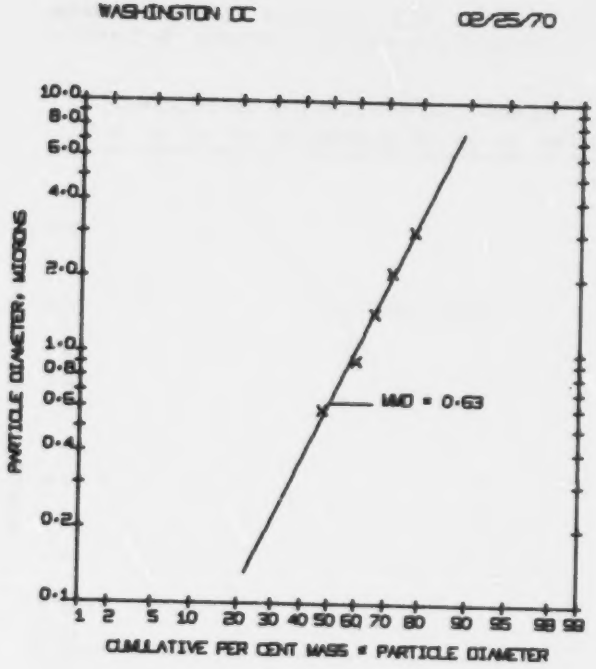

Figure G-3. Particle size distribution curve, Washington, D. C., February 25, 1970.

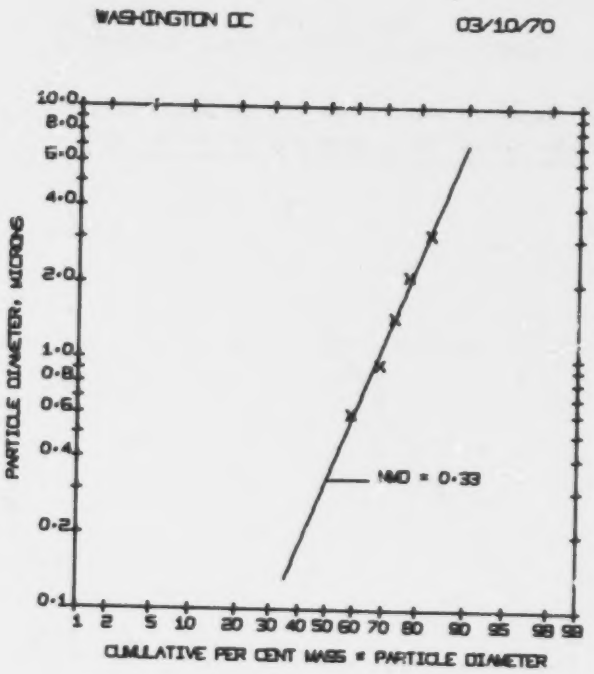

Figure G-4. Particle size distribution curve, Washington, D. C., March 10, 1970.

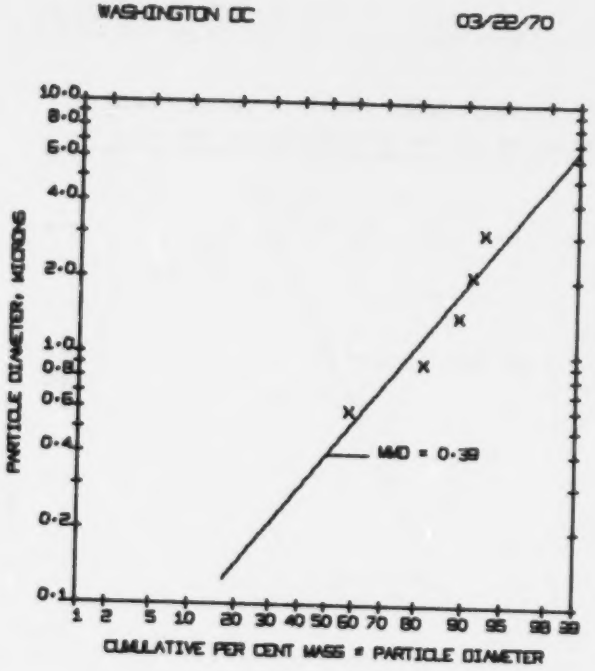

Figure G-5. Particle size distribution curve, Washington, D.C., March 22, 1970.

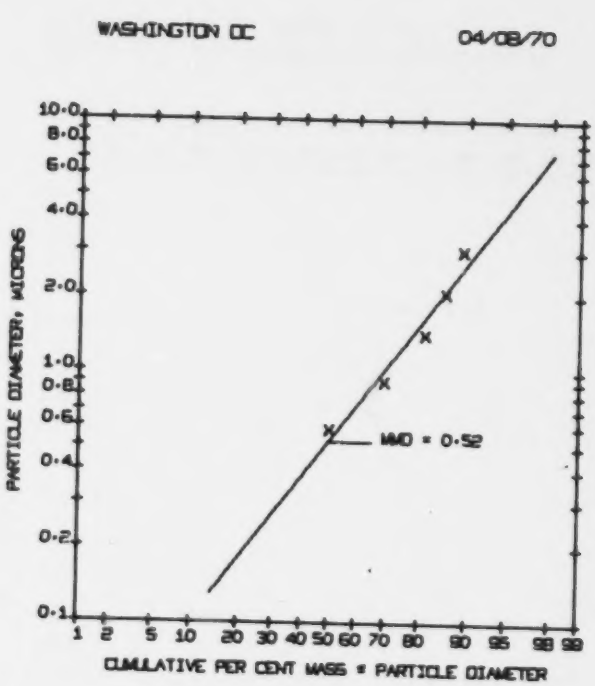

Figure G-6. Particle size distribution curve, Washington, D.C., April 8, 1970.

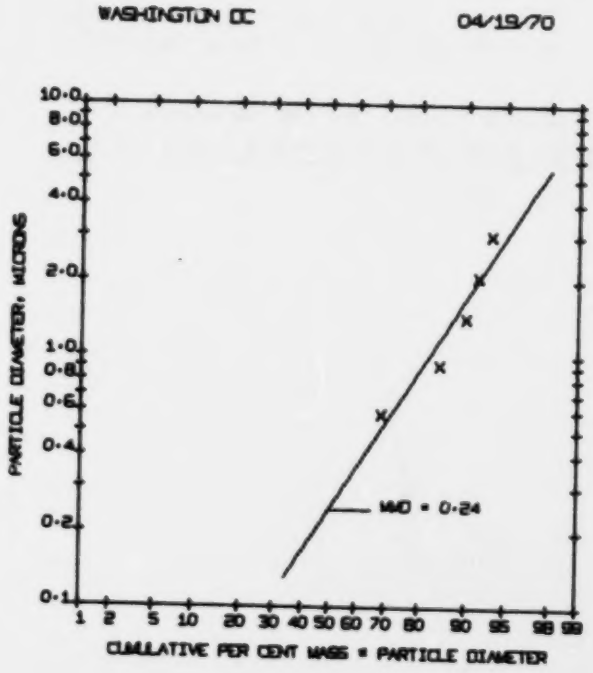

Figure G-7. Particle size distribution curve, Washington, D. C. April 19, 1970.

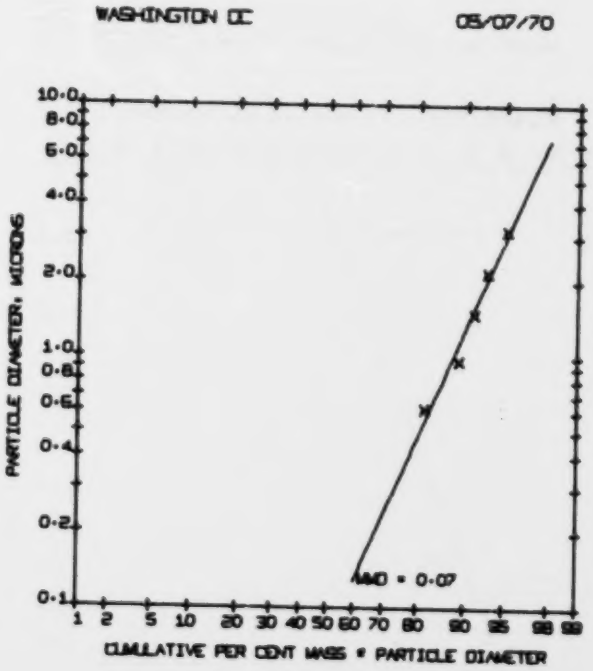

Figure G-8. Particle size distribution curve, Washington, D.C., May 7, 1970.

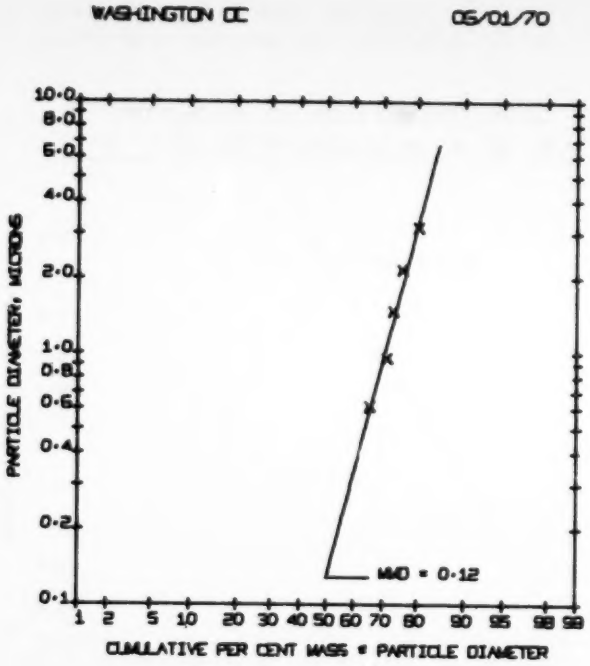

Figure G-9. Particle size distribution curve, Washington, D.C., June 1, 1970.

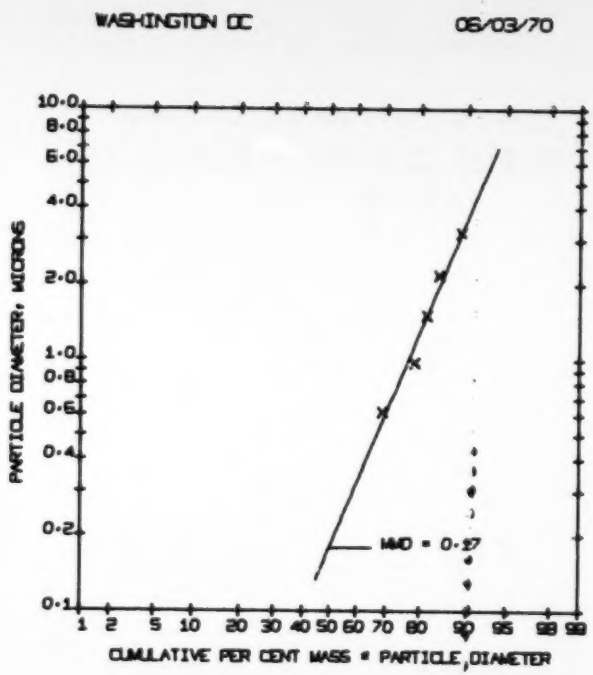

Figure G-10. Particle size distribution curve, Washington, D. C., June 3, 1970.

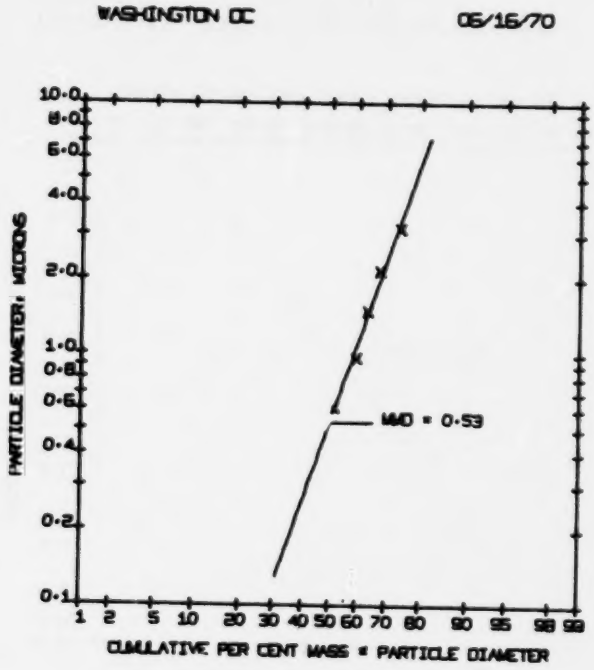

Figure G-11. Particle size distribution curve, Washington, D.C., June 16, 1970.

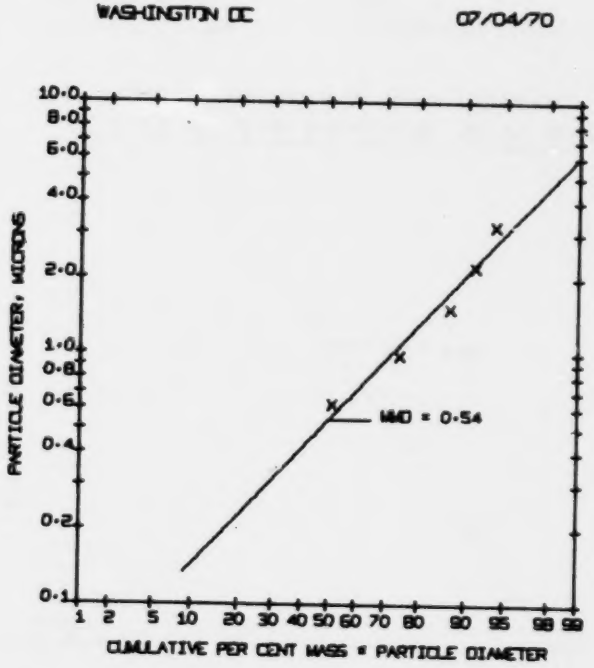

Figure G-12. Particle size distribution curve, Washington, D.C., July 4, 1970.

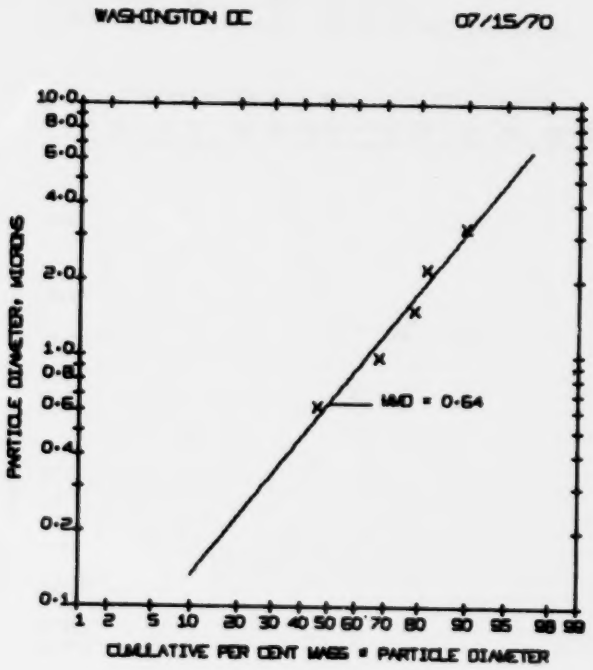

Figure G-13. Particle size distribution curve, Washington, D. C.,July 15, 1970.

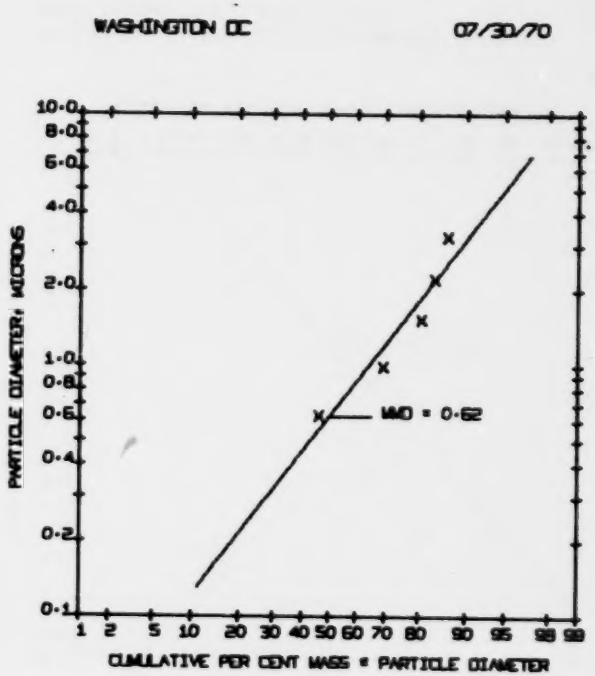

Figure G-14. Particle size distribution curve, Washington, D. C.,July 30, 1970.

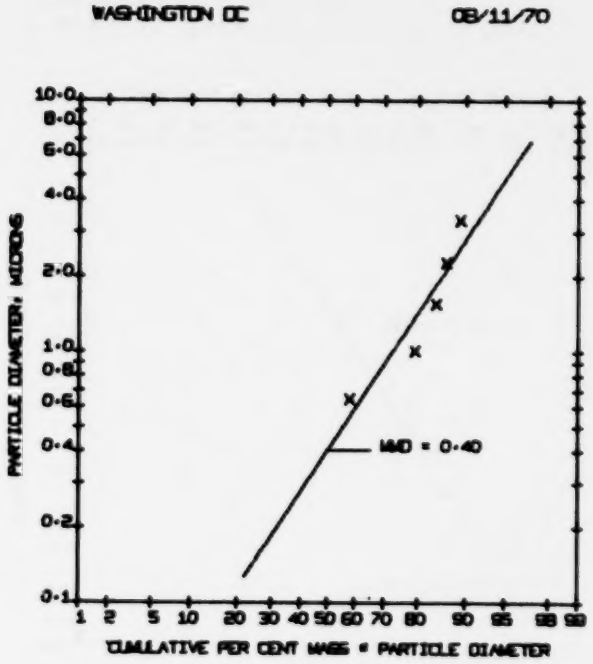

Figure G-15. Particle size distribution curve, Washington, D.C., August 11, 1970.

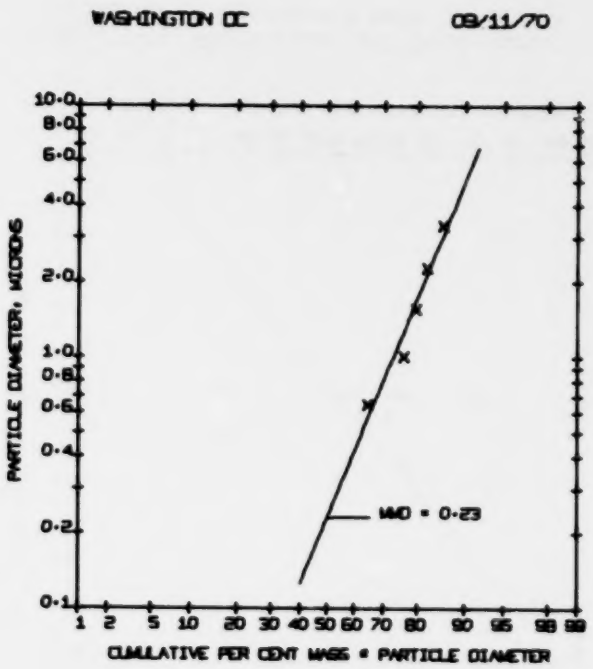

Figure G-16. Particle size distribution curve, Washington, D.C., September 11, 1970.

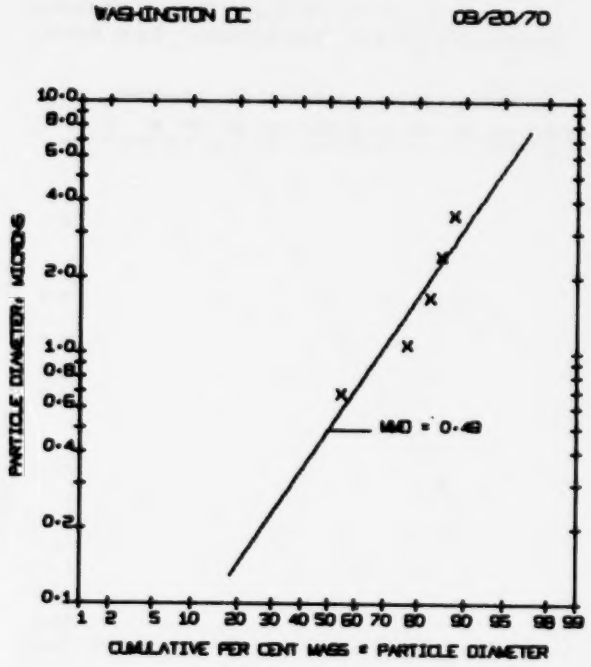

Figure G-17. Particle size distribution curve, Washington, D. C., September 20, 1970.

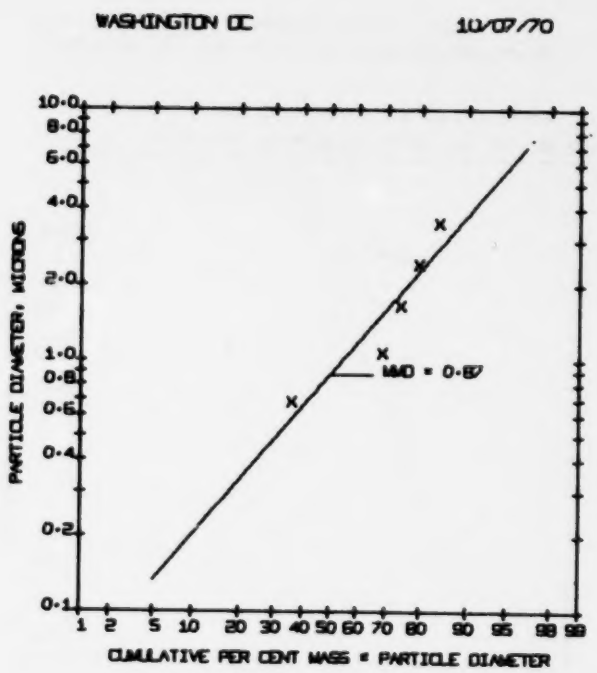

Figure G-18. Particle size distribution curve, Washington, D. C., October 7, 1970.

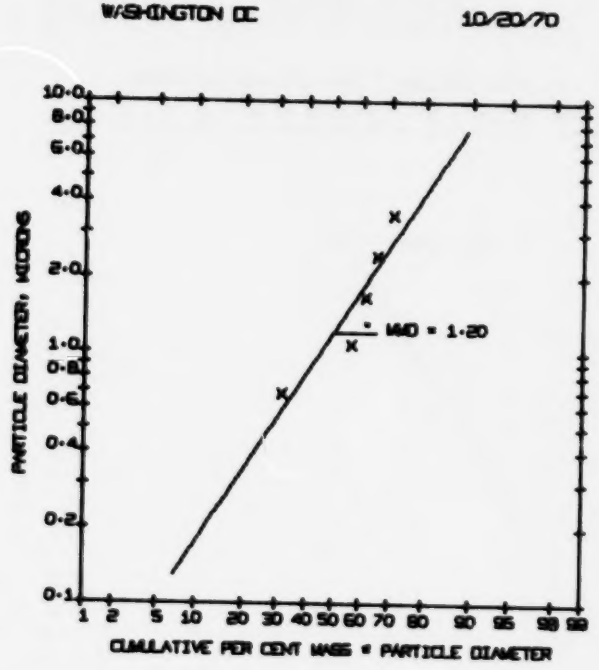

Figure G-19. Particle size distribution curve, Washington, D.C., October 20, 1970.

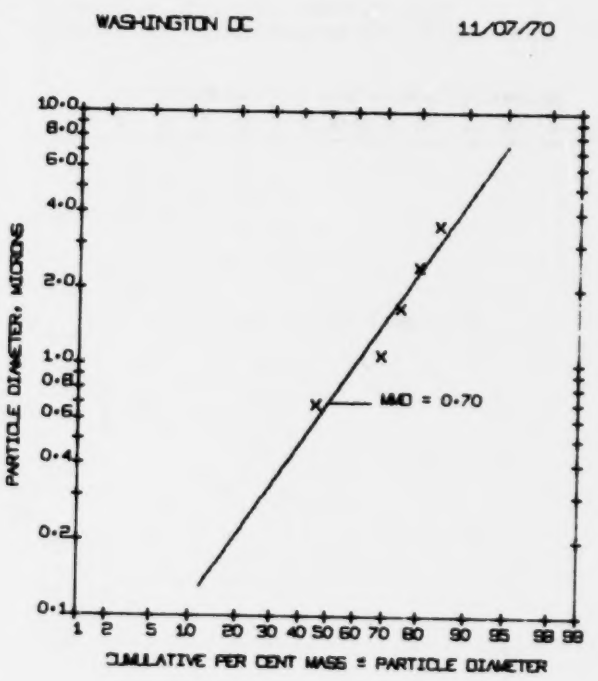

Figure G-20. Particle size distribution curve, Washington D.C., November 7, 1970.

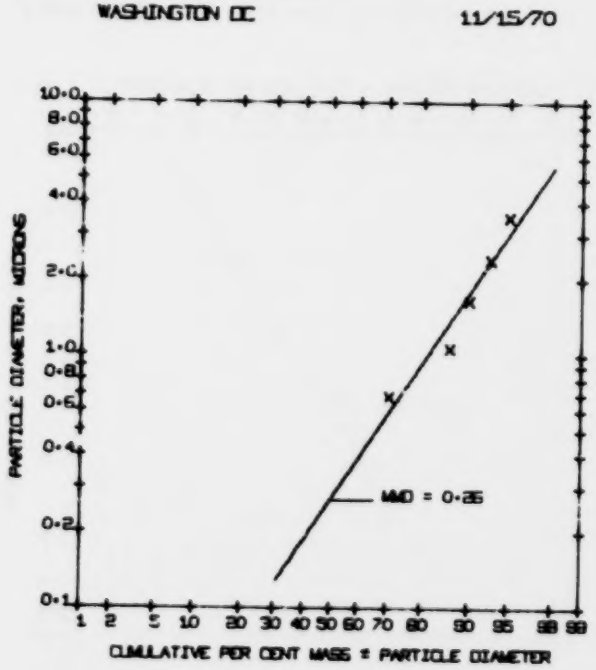

Figure G-21. Particle size distribution curve, Washington, D.C., November 15, 1970.

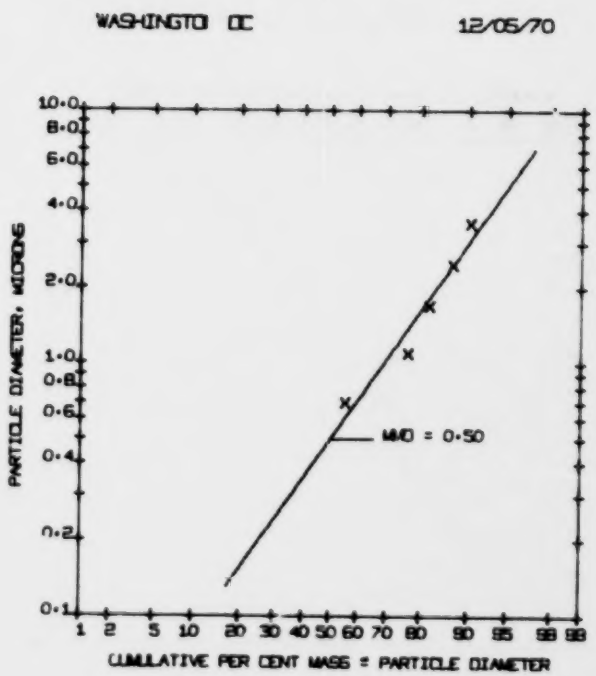

Figure G-22. Particle size distribution curve, Washington, D.C., December 5, 1970.

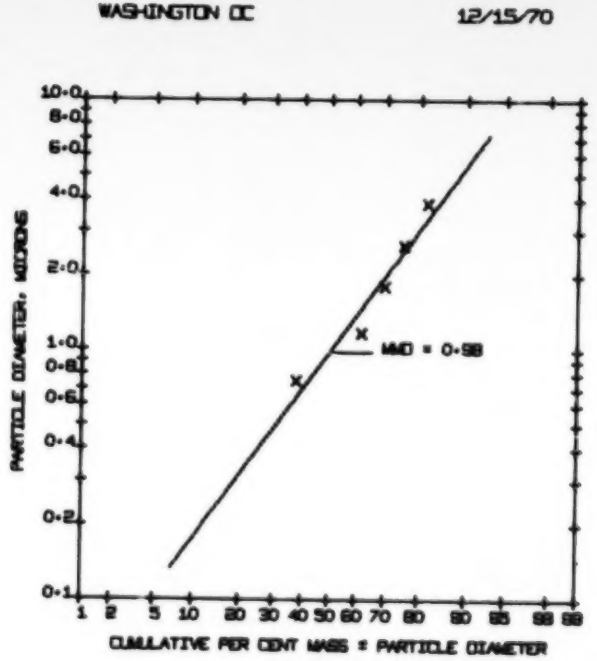

Figure G-23. Particle size distribution curve, Washington, D.C., December 15, 1970.